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(54) **MATERIALS FOR ORGANIC LIGHT EMITTING DIODE**

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Related U.S. Application Data

(63) Continuation of application No. 13/195,544, filed on Aug. 1, 2011, now abandoned, and a continuation-in-part of application No. 12/044,234, filed on Mar. 7, 2008, now Pat. No. 8,431,243.

(60) Provisional application No. 60/905,758, filed on Mar. 8, 2007.

(51) **Int. Cl.**

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H01L 51/00	(2006.01)
C07F 15/00	(2006.01)
H01L 51/50	(2006.01)

(52) **U.S. Cl.**

CPC ***H01L 51/0085*** (2013.01); ***C07F 15/0033*** (2013.01); ***C09K 11/06*** (2013.01); *C09K 2211/1029* (2013.01); *C09K 2211/185* (2013.01); *H01L 51/0081* (2013.01); *H01L 51/5016* (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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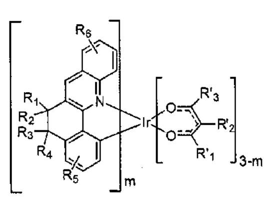
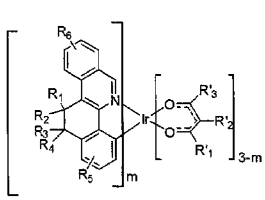
(57) **ABSTRACT**

Organometallic compounds comprising a phenylquinoline or phenylisoquinoline ligand having the quinoline or isoquinoline linked to the phenyl ring of the phenylquinoline or phenylisoquinoline, respectively, via two carbon atoms. These compounds also comprise a substituent other than hydrogen and deuterium on the quinoline, isoquinoline or linker. These compounds may be used as red emitters in phosphorescent OLEDs. In particular, these compounds may provide stable, narrow and efficient red emission.

18 Claims, 4 Drawing Sheets





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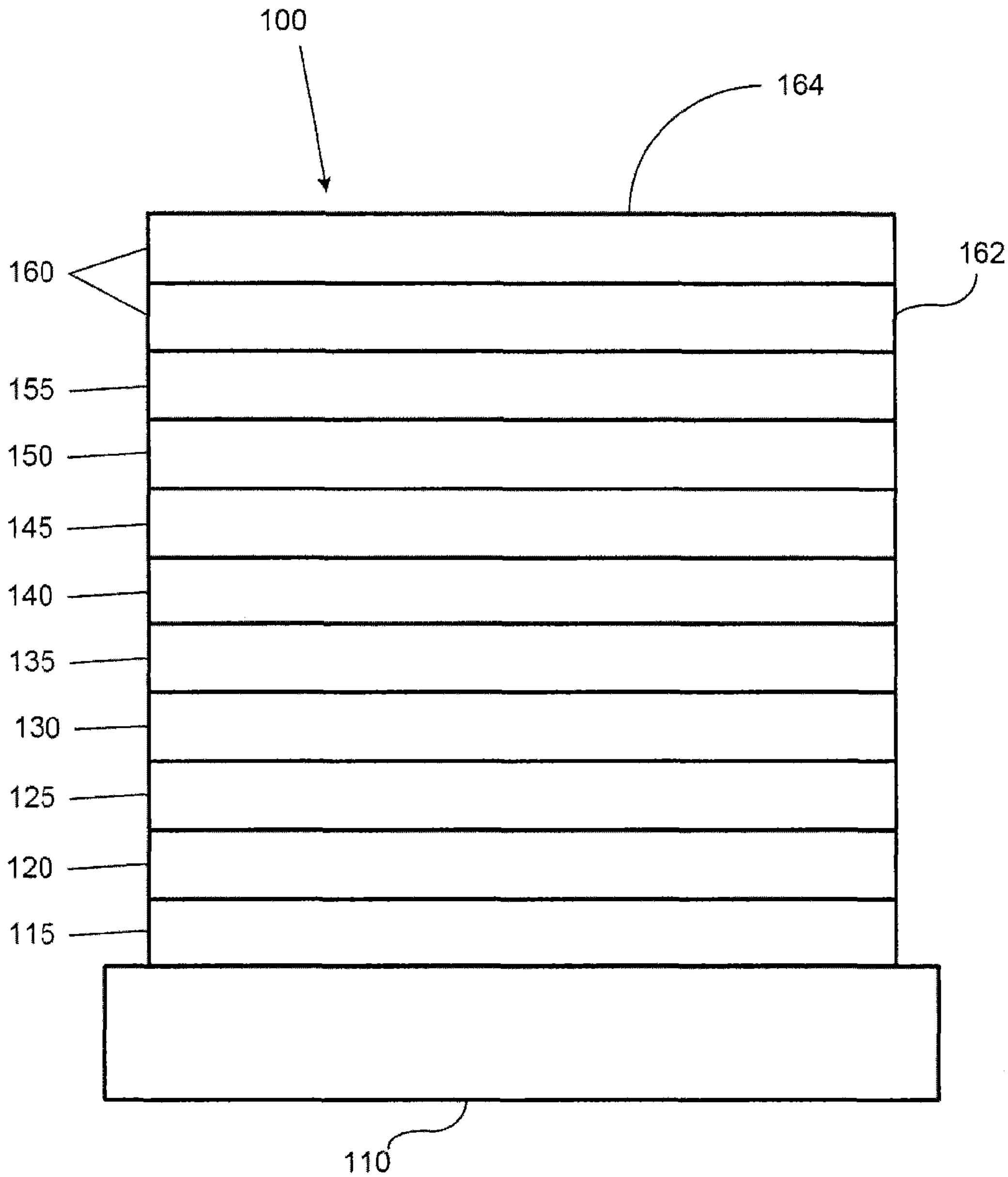


FIGURE 1

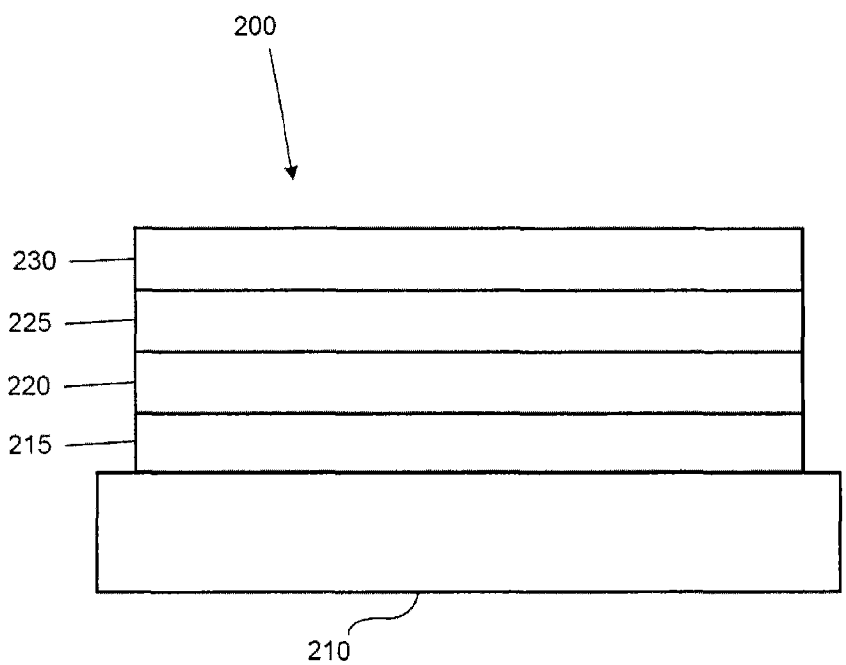


FIGURE 2

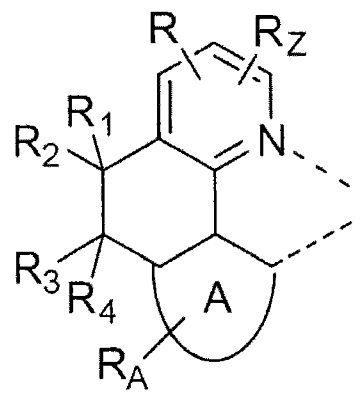
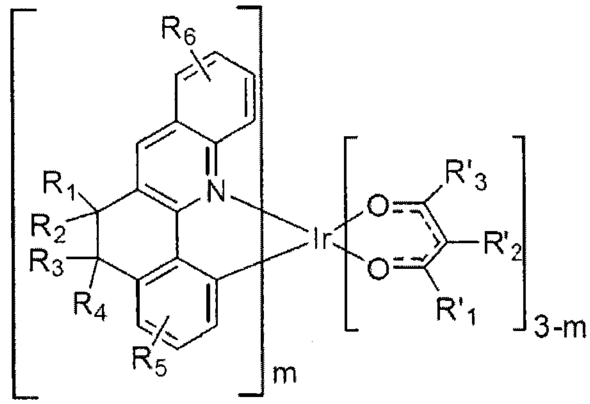


FIGURE 3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R4
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R'3
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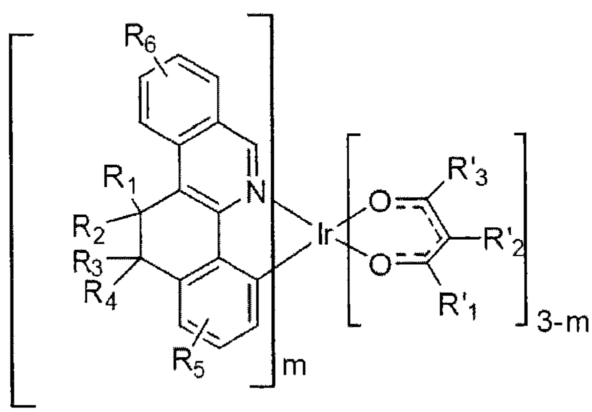
R6
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FIGURE 4

MATERIALS FOR ORGANIC LIGHT EMITTING DIODE

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 13/195,544, filed Aug. 1, 2011(now abandoned). This application is also a continuation-in-part (CIP) of U.S. application Ser. No. 12/044, 234, filed Mar. 7, 2008,now U.S. Pat. No. 8,431,243, which claims the benefit of U.S. Provisional Application No. 60/905,758, filed Mar. 8, 2007. Each of the aforementioned related patent applications is expressly incorporated herein by reference in its entirety.

PARTIES TO A JOINT RESEARCH AGREEMENT

The claimed invention was made by, on behalf of, and/or in connection with one or more of the following parties to a joint university corporation research agreement: Regents of the University of Michigan, Princeton University, The University of Southern California, and the Universal Display Corporation. The agreement was in effect on and before the date the claimed invention was made, and the claimed invention was made as a result of activities undertaken within the scope of the agreement.

FIELD OF THE INVENTION

The present invention relates to organic light emitting devices (OLEDs). More specifically, the present invention is related to organometallic compounds comprising a phenylquinoline or phenylisoquinoline ligand having the quinoline or isoquinoline linked to the phenyl ring of the phenylquinoline or phenylisoquinoline, respectively. The ligand also contains a bulky substituent on the quinoline, isoquinoline or two carbon atom linker. These compounds may be used in OLEDs to provide devices with improved lifetime and color. In particular, these compounds may be especially useful as stable, narrow and efficient red emissive compounds.

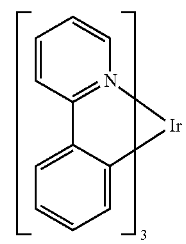
BACKGROUND

Opto-electronic devices that make use of organic materials are becoming increasingly desirable for a number of reasons. Many of the materials used to make such devices are relatively inexpensive, so organic opto-electronic devices have the potential for cost advantages over inorganic devices. In addition, the inherent properties of organic materials, such as their flexibility, may make them well suited for particular applications such as fabrication on a flexible substrate. Examples of organic opto-electronic devices include organic light emitting devices (OLEDs), organic phototransistors, organic photovoltaic cells, and organic photodetectors. For OLEDs, the organic materials may have performance advantages over conventional materials. For example, the wavelength at which an organic emissive layer emits light may generally be readily tuned with appropriate dopants.

OLEDs make use of thin organic films that emit light when voltage is applied across the device. OLEDs are becoming an increasingly interesting technology for use in applications such as flat panel displays, illumination, and backlighting. Several OLED materials and configurations are described in U.S. Pat. Nos. 5,844,363, 6,303,238, and 5,707,745, which are incorporated herein by reference in their entirety.

One application for phosphorescent emissive molecules is a full color display. Industry standards for such a display call for pixels adapted to emit particular colors, referred to as "saturated" colors. In particular, these standards call for saturated red, green, and blue pixels. Color may be measured using CIE coordinates, which are well known to the art.

One example of a green emissive molecule is tris(2-phenylpyridine) iridium, denoted $Ir(ppy)_3$, which has the following structure:



In this, and later figures herein, we depict the dative bond from nitrogen to metal (here, Ir) as a straight line.

As used herein, the term "organic" includes polymeric materials as well as small molecule organic materials that may be used to fabricate organic opto-electronic devices. "Small molecule" refers to any organic material that is not a polymer, and "small molecules" may actually be quite large. Small molecules may include repeat units in some circumstances. For example, using a long chain alkyl group as a substituent does not remove a molecule from the "small molecule" class. Small molecules may also be incorporated into polymers, for example as a pendent group on a polymer backbone or as a part of the backbone. Small molecules may also serve as the core moiety of a dendrimer, which consists of a series of chemical shells built on the core moiety. The core moiety of a dendrimer may be a fluorescent or phosphorescent small molecule emitter. A dendrimer may be a "small molecule," and it is believed that all dendrimers currently used in the field of OLEDs are small molecules.

As used herein, "top" means furthest away from the substrate, while "bottom" means closest to the substrate. Where a first layer is described as "disposed over" a second layer, the first layer is disposed further away from substrate. There may be other layers between the first and second layer, unless it is specified that the first layer is "in contact with" the second layer. For example, a cathode may be described as "disposed over" an anode, even though there are various organic layers in between.

As used herein, "solution processable" means capable of being dissolved, dispersed, or transported in and/or deposited from a liquid medium, either in solution or suspension form.

A ligand may be referred to as "photoactive" when it is believed that the ligand directly contributes to the photoactive properties of an emissive material. A ligand may be referred to as "ancillary" when it is believed that the ligand does not contribute to the photoactive properties of an emissive material, although an ancillary ligand may alter the properties of a photoactive ligand.

As used herein, and as would be generally understood by one skilled in the art, a first "Highest Occupied Molecular Orbital" (HOMO) or "Lowest Unoccupied Molecular Orbital" (LUMO) energy level is "greater than" or "higher than" a second HOMO or LUMO energy level if the first energy level is closer to the vacuum energy level. Since ionization potentials (IP) are measured as a negative energy relative to a vacuum level, a higher HOMO energy level corresponds to an IP having a smaller absolute value (an IP that is less negative). Similarly, a higher LUMO energy level corresponds to an electron affinity (EA) having a smaller absolute value (an EA that is less negative). On a conventional energy level diagram, with the vacuum level at the top, the LUMO energy level of a material is higher than the HOMO energy level of the same material. A "higher" HOMO or LUMO energy level appears closer to the top of such a diagram than a "lower" HOMO or LUMO energy level.

As used herein, and as would be generally understood by one skilled in the art, a first work function is "greater than" or "higher than" a second work function if the first work function has a higher absolute value. Because work functions are generally measured as negative numbers relative to vacuum level, this means that a "higher" work function is more negative. On a conventional energy level diagram, with the vacuum level at the top, a "higher" work function is illustrated as further away from the vacuum level in the downward direction. Thus, the definitions of HOMO and LUMO energy levels follow a different convention than work functions.

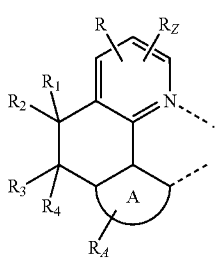
More details on OLEDs, and the definitions described above, can be found in U.S. Pat. No. 7,279,704, which is incorporated herein by reference in its entirety.

SUMMARY OF THE INVENTION

Organometallic compounds comprising a phenylquinoline or phenylisoquinoline ligand having the quinoline or isoquinoline linked to the phenyl ring of the phenylquinoline or phenylisoquinoline, respectively, via a carbon linker are provided. The compounds also comprise a bulky substituent on the quinoline, isoquinoline, or linker. The compounds have the formula $M(L_1)_x(L_2)_y(L_3)_z$.

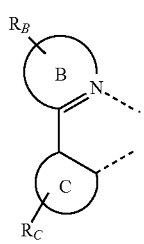
The ligand L_1 is

Formula I



The ligand L_2 is

Formula II



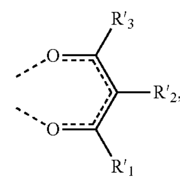
The ligand L_3 is a third ligand.

Each L_1, L_2 and L_3 can be the same or different. M is a metal having an atomic number greater than 40. Preferably, M is Ir. x is 1, 2, or 3. y is 0, 1, or 2. z is 0, 1, or 2. x+y+z is the oxidation state of the metal M. R is a carbocyclic or heterocyclic ring fused to the pyridine ring. R is optionally further substituted with R'. A, B, and C are each independently a 5 or 6-membered carbocyclic or heterocyclic ring. R', R_Z, R_A, R_B, and R_C may represent mono, di, tri, or tetra substitutions. Each of R_1, R_2, R_3, R_4, R', R_Z, R_A, R_B, and R_C are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof. At least one of R_1, R_2, R_3, R_4, and R' is not hydrogen or deuterium. Any two adjacent R_1, R_2, R_3, R_4, and R' are optionally linked to form an alkyl ring.

In one aspect, at least one of R_1, R_2, R_3, R_4, and R' is an alkyl. In another aspect, R' is not hydrogen or deuterium. Preferably, at least one of R_1, R_2, R_3, R_4, and R' is an alkyl having more than 2 carbon atoms. More preferably, at least one of R_1, R_2, R_3, R_4, and R' is isobutyl.

In one aspect, L_3 is a monoanionic bidentate ligand.

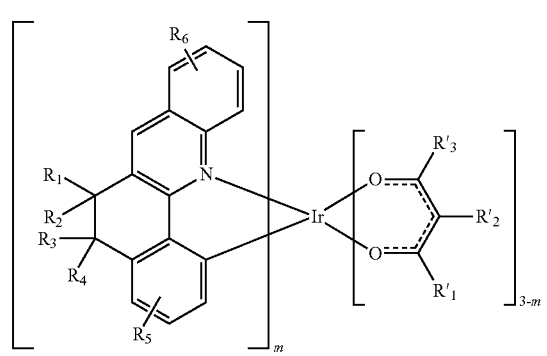
In another aspect, L_3 is



and R'_1, R'_2, and R'_3 are each independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof. Preferably, R'_2 is hydrogen. More preferably, at least one of R'_1, R'_2, and R'_3 contains a branched alkyl moiety with branching at a position further than the α position to the carbonyl group. Most preferably, at least one of R'_1 and R'_3 is isobutyl.

In one aspect, the compound has the formula:

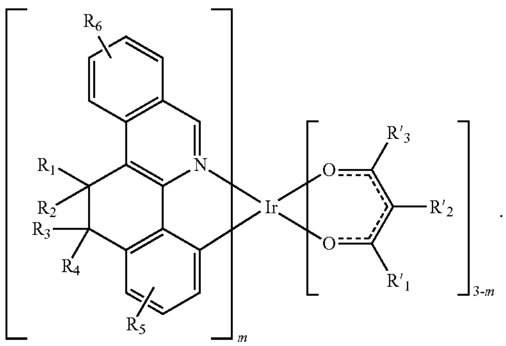
Formula III



R_5 and R_6 may represent mono, di, tri, or tetra substitutions. Each of R_5 and R_6 are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof. At least one of R_1, R_2, R_3, R_4, and R_6 is not hydrogen or deuterium. m is 1, 2, or 3.

in another aspect, the compound has the formula:

Formula IV

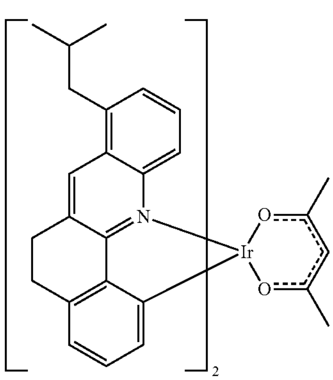


R_5 and R_6 may represent mono, di, tri, or tetra substitutions. Each of R_5 and R_6 are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof. At least one of R_1, R_2, R_3, R_4, and R_6 is not hydrogen or deuterium. m is 1, 2, or 3.

In one aspect, the compound is homoleptic. In another aspect, the compound is heteroleptic.

Specific non-limiting examples of organometallic compounds comprising a phenylquinoline or phenylisoquinoline ligand having the quinoline or isoquinoline linked to the phenyl ring of the phenylquinoline or phenylisoquinoline, respectively, are provided. These compounds also have a bulky substituent on the quinoline, isoquinoline, or linker. In one aspect, the compound is selected from the group consisting of:

1



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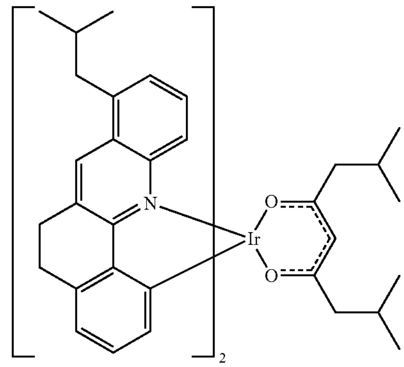

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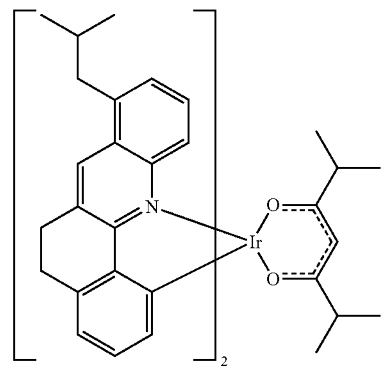

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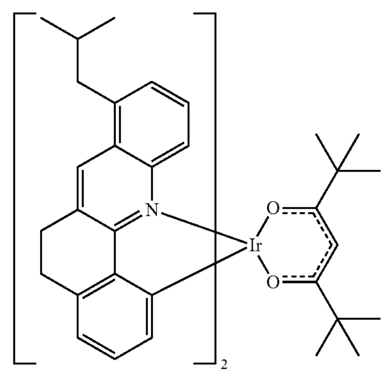

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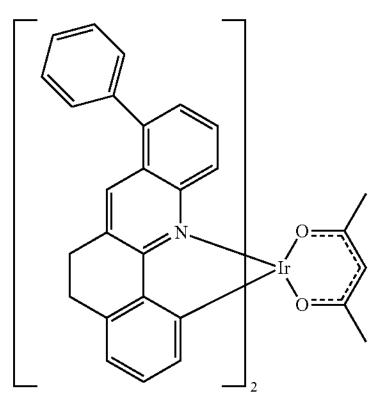

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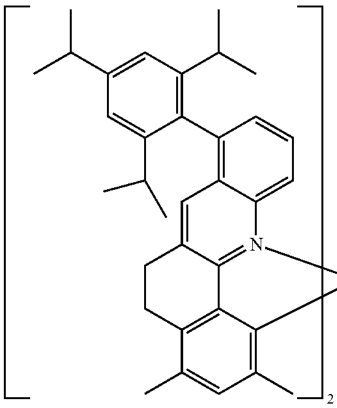

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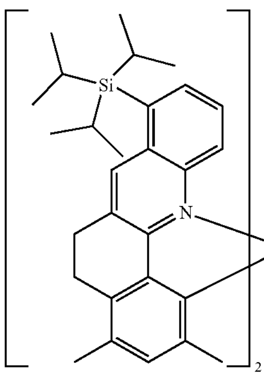

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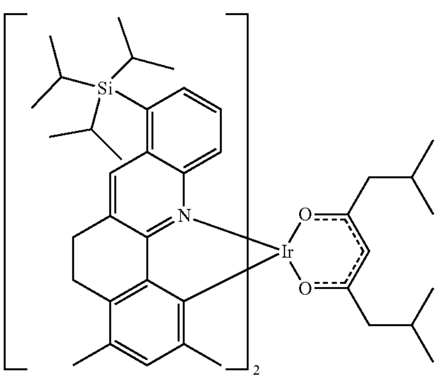

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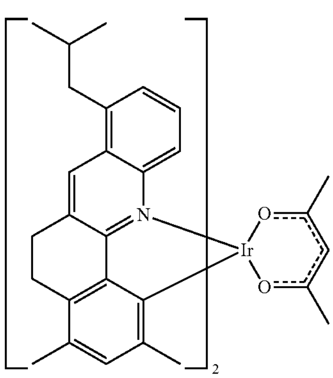

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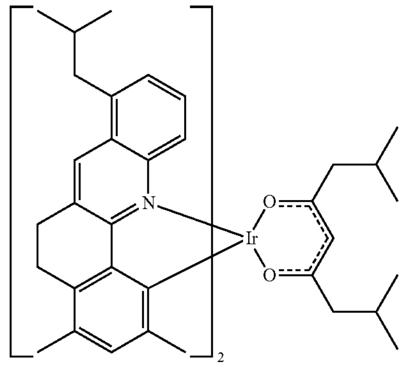

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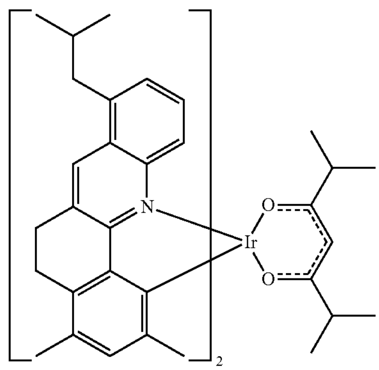

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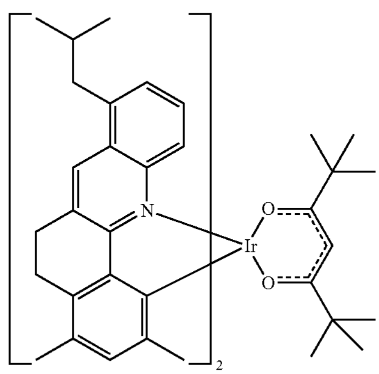

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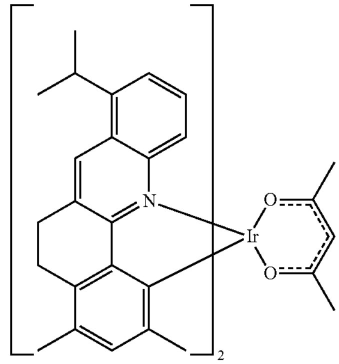

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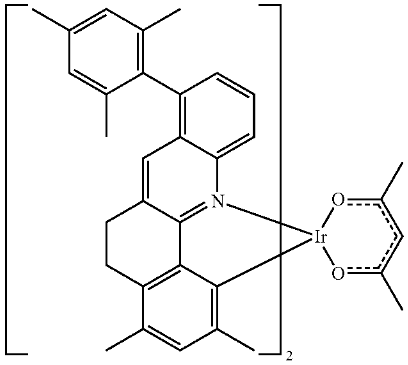

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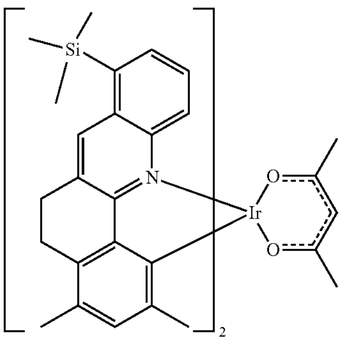

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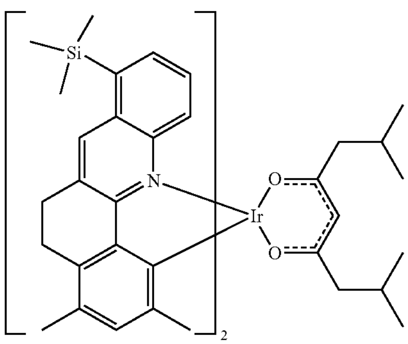

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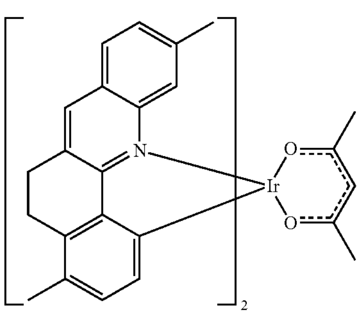

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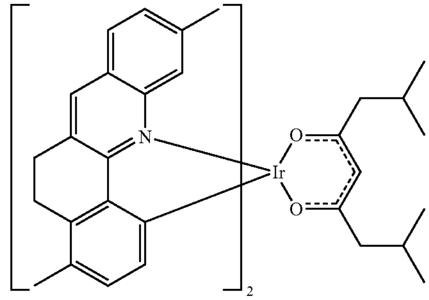

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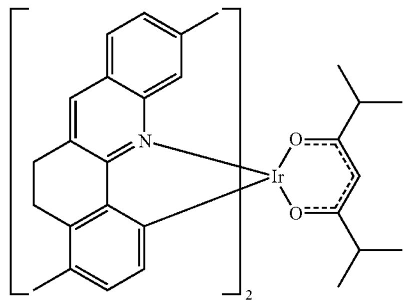

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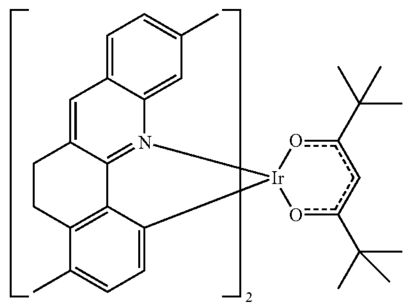

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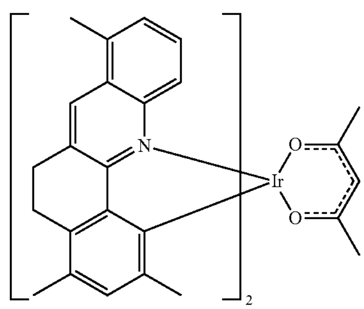

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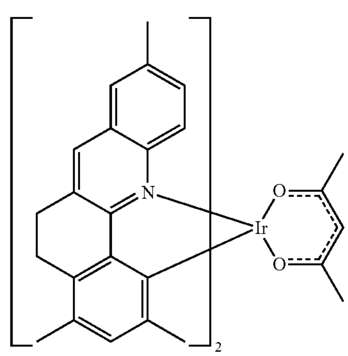

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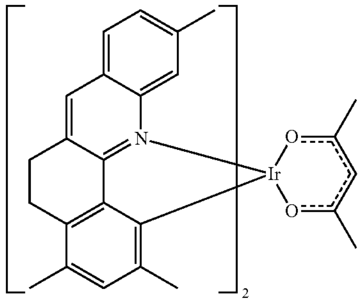

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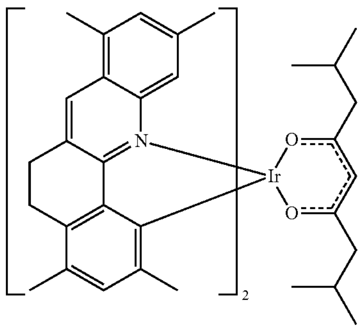

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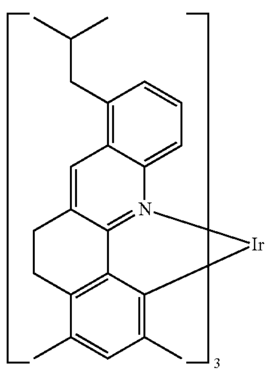

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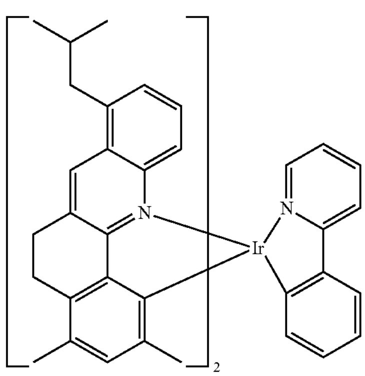

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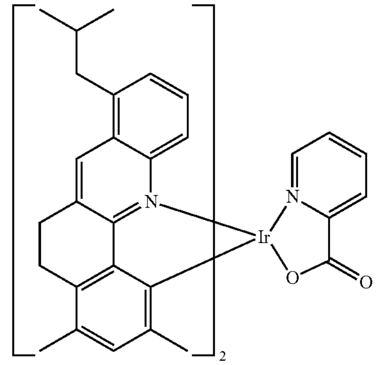

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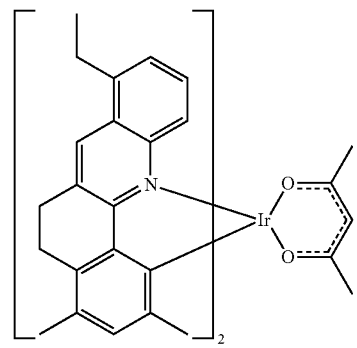

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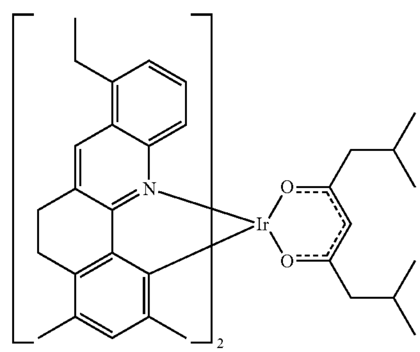

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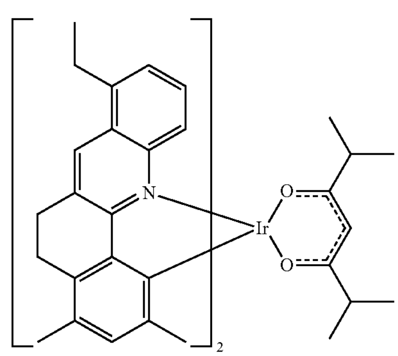

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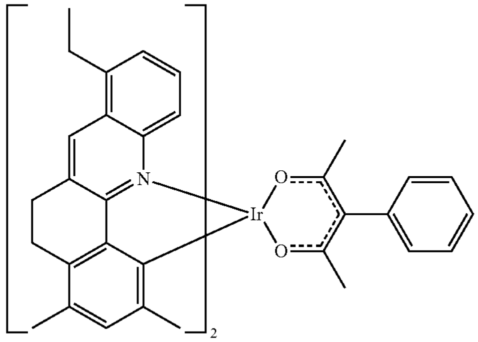

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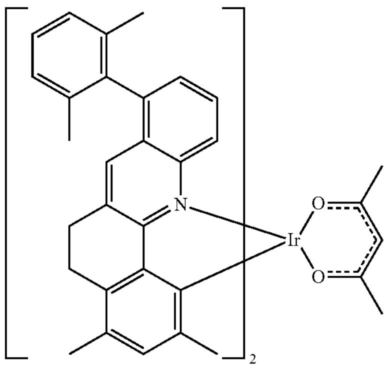

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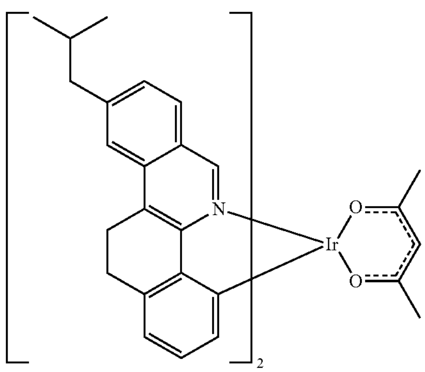

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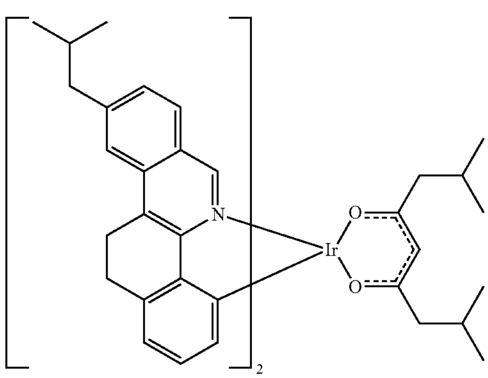

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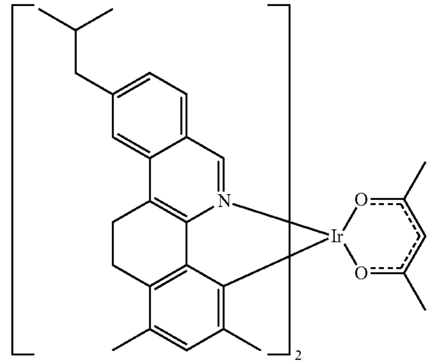

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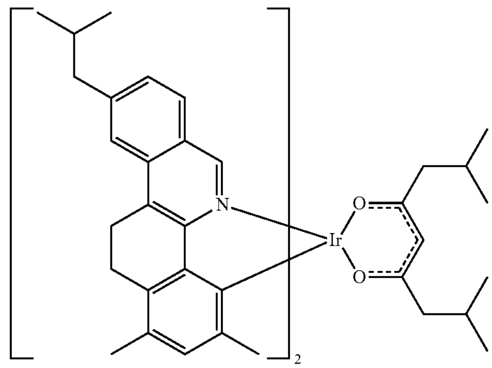

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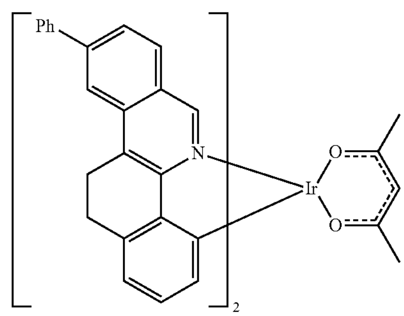

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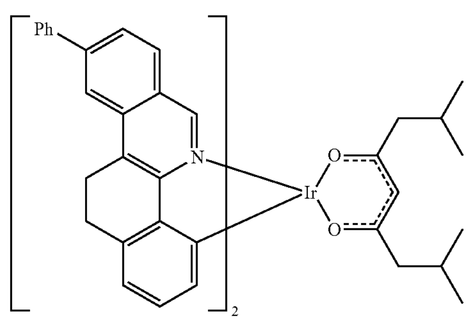

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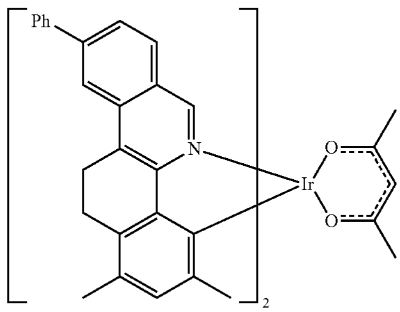

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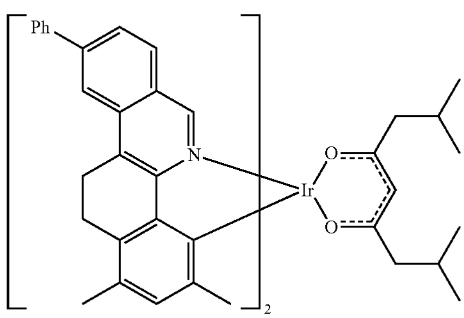

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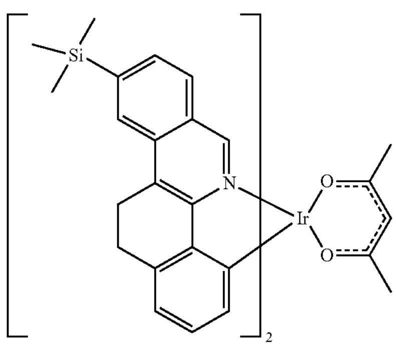

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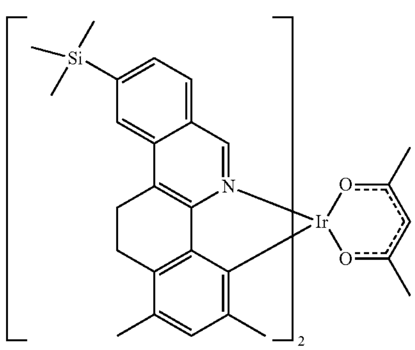

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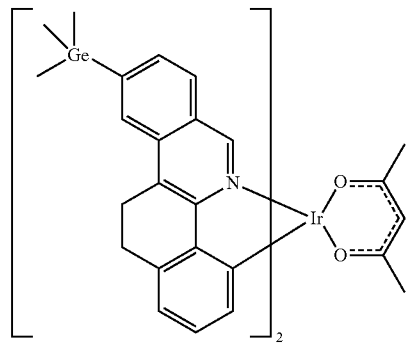

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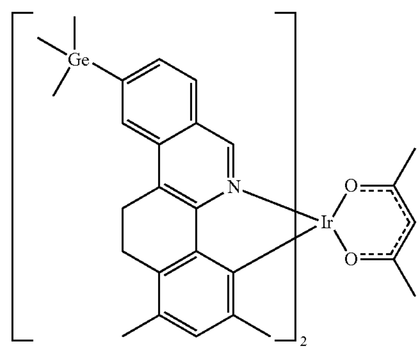

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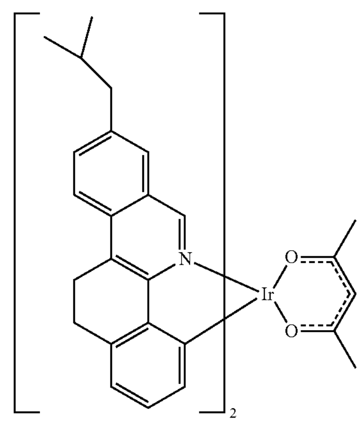

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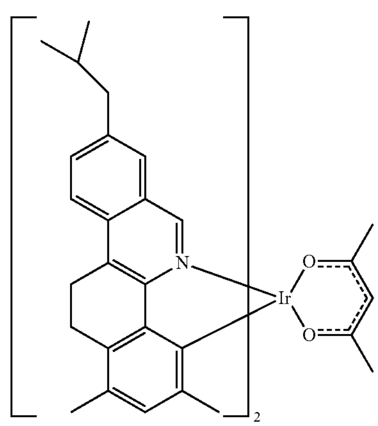
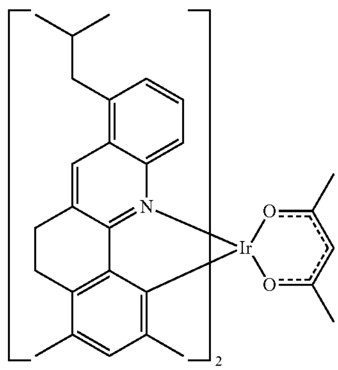
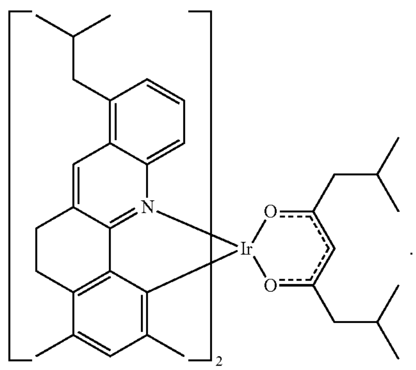


.

Preferably, the compound is:



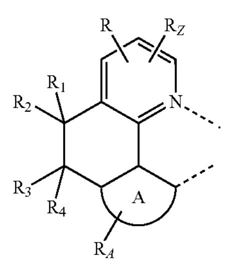
or



Additionally, a first device comprising a first organic light emitting device is provided. The organic light emitting device further comprises an anode, a cathode, and an organic layer, disposed between the anode and the cathode. The organic layer further comprises a compound having the formula $M(L_1)_x(L_2)_y(L_3)_z$, as described above.

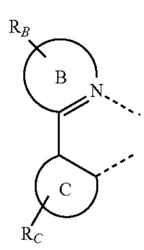
The ligand L_1 is

Formula I



The ligand L_2 is

Formula II



The ligand L_3 is a third ligand.

Each L_1, L_2 and L_3 can be the same or different. M is a metal having an atomic number greater than 40. x is 1, 2, or 3.

y is 0, 1, or 2. z is 0, 1, or 2. x+y+z is the oxidation state of the metal M. R is a carbocyclic or heterocyclic ring fused to the pyridine. R is optionally further substituted with R'. A, B, and C are each independently a 5 or 6-membered carbocyclic or heterocyclic ring. R', R_Z, R_A, R_B, and R_C may represent mono, di, tri, or tetra substitutions. Each of R_1, R_2, R_3, R_4, R', R_Z, R_A, R_B, and R_C are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof. At least one of R_1, R_2, R_3, R_4, and R' is not hydrogen or deuterium. Any two adjacent R_1, R_2, R_3, R_4, and R' are optionally linked to form an alkyl ring.

The various specific aspects discussed above for compounds having the formula $M(L_1)_x(L_2)_y(L_3)_z$ are also applicable to a compound having $M(L_1)_x(L_2)_y(L_3)_z$ that is used in the first device. In particular, specific aspects of L_1, L_2, L_3, A, B, C, R_A, R_B, R_C, R_Z, R, R', R_1, R_2, R_3, R_4, R_5, R_6, R'_1, R'_2, R'_3, M, m Formula III and Formula IV of the compound having the formula $M(L_1)_x(L_2)_y(L_3)_z$ are also applicable to a compound having $M(L_1)_x(L_2)_y(L_3)_z$ that is used in the first device.

In one aspect, the first device is a consumer product. In another aspect, the first device is an organic light emitting device. In yet another aspect, the first device comprises a lighting panel.

In one aspect, the organic layer is an emissive layer and the compound is an emissive dopant. In another aspect, the organic layer further comprises a host. Preferably, the host is a metal 8-hydroxyquinolate.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows an organic light emitting device.

FIG. **2** shows an inverted organic light emitting device that does not have a separate electron transport layer.

FIG. **3** shows a phenylquinoline or phenylisoquinoline ligand with the quinoline or isoquinoline linked to the phenyl ring of the phenylquinoline or phenylisoquinoline, respectively, and comprising a bulky substituent.

FIG. **4** shows exemplary organometallic compounds comprising phenylquinoline or phenylisoquinoline ligand with the quinoline or isoquinoline linked to the phenyl ring of the phenylquinoline or phenylisoquinoline, respectively, and comprising a bulky substituent.

DETAILED DESCRIPTION

Generally, an OLED comprises at least one organic layer disposed between and electrically connected to an anode and a cathode. When a current is applied, the anode injects holes and the cathode injects electrons into the organic layer(s). The injected holes and electrons each migrate toward the oppositely charged electrode. When an electron and hole localize on the same molecule, an "exciton," which is a localized electron-hole pair having an excited energy state, is formed. Light is emitted when the exciton relaxes via a photoemissive mechanism. In some cases, the exciton may be localized on an excimer or an exciplex. Non-radiative mechanisms, such as thermal relaxation, may also occur, but are generally considered undesirable.

The initial OLEDs used emissive molecules that emitted light from their singlet states ("fluorescence") as disclosed, for example, in U.S. Pat. No. 4,769,292, which is incorporated by reference in its entirety. Fluorescent emission generally occurs in a time frame of less than 10 nanoseconds.

More recently, OLEDs having emissive materials that emit light from triplet states ("phosphorescence") have been demonstrated. Baldo et al., "Highly Efficient Phosphorescent Emission from Organic Electroluminescent Devices," Nature, vol. 395, 151-154, 1998; ("Baldo-I") and Baldo et al., "Very high-efficiency green organic light-emitting devices based on electrophosphorescence," Appl. Phys. Lett., vol. 75, No. 3, 4-6 (1999) ("Baldo-II"), which are incorporated by reference in their entireties. Phosphorescence is described in more detail in U.S. Pat. No. 7,279,704 at cols. 5-6, which are incorporated by reference.

FIG. **1** shows an organic light emitting device **100**. The figures are not necessarily drawn to scale. Device **100** may include a substrate **110**, an anode **115**, a hole injection layer **120**, a hole transport layer **125**, an electron blocking layer **130**, an emissive layer **135**, a hole blocking layer **140**, an electron transport layer **145**, an electron injection layer **150**, a protective layer **155**, and a cathode **160**. Cathode **160** is a compound cathode having a first conductive layer **162** and a second conductive layer **164**. Device **100** may be fabricated by depositing the layers described, in order. The properties and functions of these various layers, as well as example materials, are described in more detail in U.S. Pat. No. 7,279,704 at cols. 6-10, which are incorporated by reference.

More examples for each of these layers are available. For example, a flexible and transparent substrate-anode combination is disclosed in U.S. Pat. No. 5,844,363, which is incorporated by reference in its entirety. An example of a p-doped hole transport layer is m-MTDATA doped with F.sub.4-TCNQ at a molar ratio of 50:1, as disclosed in U.S. Patent Application Publication No. 2003/0230980, which is incorporated by reference in its entirety. Examples of emissive and host materials are disclosed in U.S. Pat. No. 6,303,238 to Thompson et al., which is incorporated by reference in its entirety. An example of an n-doped electron transport layer is BPhen doped with Li at a molar ratio of 1:1, as disclosed in U.S. Patent Application Publication No. 2003/0230980, which is incorporated by reference in its entirety. U.S. Pat. Nos. 5,703,436 and 5,707,745, which are incorporated by reference in their entireties, disclose examples of cathodes including compound cathodes having a thin layer of metal such as Mg:Ag with an overlying transparent, electrically-conductive, sputter-deposited ITO layer. The theory and use of blocking layers is described in more detail in U.S. Pat. No. 6,097,147 and U.S. Patent Application Publication No. 2003/0230980, which are incorporated by reference in their entireties. Examples of injection layers are provided in U.S. Patent Application Publication No. 2004/0174116, which is incorporated by reference in its entirety. A description of protective layers may be found in U.S. Patent Application Publication No. 2004/0174116, which is incorporated by reference in its entirety.

FIG. **2** shows an inverted OLED **200**. The device includes a substrate **210**, a cathode **215**, an emissive layer **220**, a hole transport layer **225**, and an anode **230**. Device **200** may be fabricated by depositing the layers described, in order. Because the most common OLED configuration has a cathode disposed over the anode, and device **200** has cathode **215** disposed under anode **230**, device **200** may be referred to as an "inverted" OLED. Materials similar to those described with respect to device **100** may be used in the corresponding layers of device **200**. FIG. **2** provides one example of how some layers may be omitted from the structure of device **100**.

The simple layered structure illustrated in FIGS. **1** and **2** is provided by way of non-limiting example, and it is understood that embodiments of the invention may be used in connection with a wide variety of other structures. The specific materials and structures described are exemplary in nature, and other materials and structures may be used. Functional OLEDs may be achieved by combining the various layers described in different ways, or layers may be omitted entirely, based on design, performance, and cost factors. Other layers not specifically described may also be included. Materials other than those specifically described may be used. Although many of the examples provided herein describe various layers as comprising a single material, it is understood that combinations of materials, such as a mixture of host and dopant, or more generally a mixture, may be used. Also, the layers may have various sublayers. The names given to the various layers herein are not intended to be strictly limiting. For example, in device **200**, hole transport layer **225** transports holes and injects holes into emissive layer **220**, and may be described as a hole transport layer or a hole injection layer. In one embodiment, an OLED may be described as having an "organic layer" disposed between a cathode and an anode. This organic layer may comprise a single layer, or may further comprise multiple layers of different organic materials as described, for example, with respect to FIGS. **1** and **2**.

Structures and materials not specifically described may also be used, such as OLEDs comprised of polymeric materials (PLEDs) such as disclosed in U.S. Pat. No. 5,247,190 to Friend et al., which is incorporated by reference in its entirety. By way of further example, OLEDs having a single organic layer may be used. OLEDs may be stacked, for example as described in U.S. Pat. No. 5,707,745 to Forrest et al, which is incorporated by reference in its entirety. The OLED structure may deviate from the simple layered structure illustrated in FIGS. **1** and **2**. For example, the substrate may include an angled reflective surface to improve out-coupling, such as a mesa structure as described in U.S. Pat. No. 6,091,195 to Forrest et al., and/or a pit structure as described in U.S. Pat. No. 5,834,893 to Bulovic et al., which are incorporated by reference in their entireties.

Unless otherwise specified, any of the layers of the various embodiments may be deposited by any suitable method. For the organic layers, preferred methods include thermal evaporation, ink-jet, such as described in U.S. Pat. Nos. 6,013,982 and 6,087,196, which are incorporated by reference in their entireties, organic vapor phase deposition (OVPD), such as described in U.S. Pat. No. 6,337,102 to Forrest et al., which is incorporated by reference in its entirety, and deposition by organic vapor jet printing (OVJP), such as described in U.S. patent application Ser. No. 10/233,470, now U.S. Pat. No. 7,431,968, which is incorporated by reference in its entirety. Other suitable deposition methods include spin coating and other solution based processes. Solution based processes are preferably carried out in nitrogen or an inert atmosphere. For the other layers, preferred methods include thermal evaporation. Preferred patterning methods include deposition through a mask, cold welding such as described in U.S. Pat. Nos. 6,294,398 and 6,468,819, which are incorporated by reference in their entireties, and patterning associated with some of the deposition methods such as ink-jet and OVJD. Other methods may also be used. The materials to be deposited may be modified to make them compatible with a particular deposition method. For example, substituents such as alkyl and aryl groups, branched or unbranched, and preferably containing at least 3 carbons, may be used in small molecules to enhance their ability to undergo solution processing. Substituents having 20 carbons or more may be used, and 3-20 carbons is a preferred range. Materials with asymmetric structures may have better solution processability than those having symmetric structures, because asymmetric materials may have a lower tendency to recrystallize. Dendrimer substituents may be used to enhance the ability of small molecules to undergo solution processing.

Devices fabricated in accordance with embodiments of the invention may be incorporated into a wide variety of consumer products, including flat panel displays, computer monitors, televisions, billboards, lights for interior or exterior illumination and/or signaling, heads up displays, fully transparent displays, flexible displays, laser printers, telephones, cell phones, personal digital assistants (PDAs), laptop computers, digital cameras, camcorders, viewfinders, micro-displays, vehicles, a large area wall, theater or stadium screen, or a sign. Various control mechanisms may be used to control devices fabricated in accordance with the present invention, including passive matrix and active matrix. Many of the devices are intended for use in a temperature range comfortable to humans, such as 18 degrees C. to 30 degrees C., and more preferably at room temperature (20-25 degrees C.).

The materials and structures described herein may have applications in devices other than OLEDs. For example, other optoelectronic devices such as organic solar cells and organic photodetectors may employ the materials and structures. More generally, organic devices, such as organic transistors, may employ the materials and structures.

The terms halo, halogen, alkyl, cycloalkyl, alkenyl, alkynyl, arylkyl, heterocyclic group, aryl, aromatic group, and heteroaryl are known to the art, and are defined in U.S. Pat. No. 7,279,704 at cols. 31-32, which are incorporated herein by reference.

A novel class of organometallic compounds is provided. The compounds comprise a phenylquinoline or phenylisoquinoline ligand having the quinoline or isoquinoline linked to the phenyl ring of the phenylquinoline or phenylisoquinoline, respectively, via two carbon atoms, e.g., a linked phenylquinoline or linked phenylisoquinoline (as illustrated in FIG. **3**). In addition, the ligand also includes at least one substituent other than hydrogen and deuterium on the quinoline, isoquinoline or two carbon atoms linking the quinoline or isoquinoline to the aromatic ring, i.e., bulky substituent. These compounds may be used as red emitters in phosphorescent OLEDs. In particular, these compounds may provide stable, narrow and efficient red emission as a result of the rigidification and addition of a bulky substituent.

The compounds disclosed herein may provide narrow red emission as a result of rigidification, which may narrow the EL spectrum. The spectrum at half maximum (FWHW) of an organic molecule may narrow as the molecules become more rigid. The compounds disclosed herein are made more rigid by linking the top portion of the ligand, e.g., a quinoline or isoquinoline, to the bottom portion of the ligand, e.g., phenyl ring. For example, the compounds may include a linked phenylquinoline or linked phenylisoquinoline. In particular, a compound comprising a 2-phenylquinoline ligand in which the quinoline has been linked to the phenyl ring may have a narrower EL spectrum. A narrow EL spectrum is a desirable property of electroluminescent materials for use in an OLED.

As discussed above, a two carbon atom linker links the quinoline or isoquinoline to the phenyl ring of the phenylquinoline or phenylisoquinoline. Without being bound by theory, it is believed that using only carbon atoms as linkers may provide better device stability, i.e., longer device lifetime, when compared to other linkers, such as those with oxygen atoms. Additionally, it is believed that two atoms in the linker backbone, rather than one atom, is desirable. One atom linker may be too small, resulting in an increased coordinating binding angle of the ligand to metal on the other side of the ligand, which may reduce the bond strength of metal to ligand, and, in turn, decrease the stability of the metal complex.

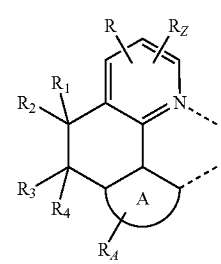
Moreover, the compounds disclosed herein may provide stable and efficient red emission as a result of having a substituent other than hydrogen and deuterium on the quinoline, isoquinoline or two carbon atoms in the linked ligand. Without being bound by theory, it is believed that the addition of a bulky substituent to the linked ligand may prevent aggregation and self quenching in the compound, thereby providing higher device efficiency.

Without being bound by theory, it may be particularly advantageous to have an alkyl substituent as the bulky group on the linked ligand because alkyls offer a wide range of tunability. In particular, an alkyl substituent may be useful for tuning the evaporation temperature, solubility, energy levels, device efficiency and narrowness of the emission spectrum of the compound. Additionally, alkyl groups can be stable functional groups chemically and in device operation. For example, a linked ligand comprising an alkyl substituent on the quinoline may provide increased efficiency.

Organometallic compounds comprising a phenylquinoline or phenylisoquinoline ligand containing a quinoline or isoquinoline linked to the phenyl ring of the phenylquinoline or phenylisoquinoline, respectively, via two carbon atoms are provided (as illustrated in FIG. **4**). The compounds also comprise a bulky substituent, i.e., not hydrogen or deuterium, on the quinoline, isoquinoline, or linker. The compounds have the formula $M(L_1)_x(L_2)_y(L_3)_z$.

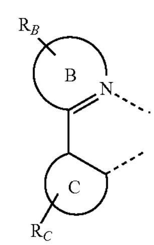
The ligand L_1 is

Formula I



The ligand L_2 is

Formula II



The ligand L_3 is a third ligand.

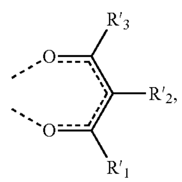
Each L_1, L_2 and L_3 can be the same or different. M is a metal having an atomic number greater than 40. Preferably, M is Ir. x is 1, 2, or 3. y is 0, 1, or 2. z is 0, 1, or 2. x+y+z is the oxidation state of the metal M. R is a carbocyclic or heterocyclic ring fused to the pyridine. R is optionally further substituted with R'. A, B, and C are each independently a 5 or 6-membered carbocyclic or heterocyclic ring. R', R_Z, R_A, R_B, and R_C may represent mono, di, tri, or tetra substitutions. Each of R_1, R_2, R_3, R_4, R', R_Z, R_A, R_B, and R_C are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof. At least one of R_1, R_2, R_3, R_4, and R' is not hydrogen or deuterium. Any two adjacent R_1, R_2, R_3, R_4, and R' are optionally linked to form an alkyl ring.

For the compounds disclosed herein, a bulky substituent is present on the quinoline, isoquinoline or two carbon atoms in the linked ligand. The bulky group may be a halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, i.e., bulky group is a substituent other than hydrogen or deuterium. Without being bound by theory, it is believed that the bulky substituent is least likely to affect the emission color of the compound If it is placed at one or more of the R_1, R_2, R_3, R_4, and R' positions.

In one aspect, at least one of R_1, R_2, R_3, R_4, and R' is an alkyl. In another aspect, R' is not hydrogen or deuterium. Preferably, at least one of R_1, R_2, R_3, R_4, and R' is an alkyl having more than 2 carbon atoms. More preferably, at least one of R_1, R_2, R_3, R_4, and R' is isobutyl.

In one aspect, L_3 is a monoanionic bidentate ligand.

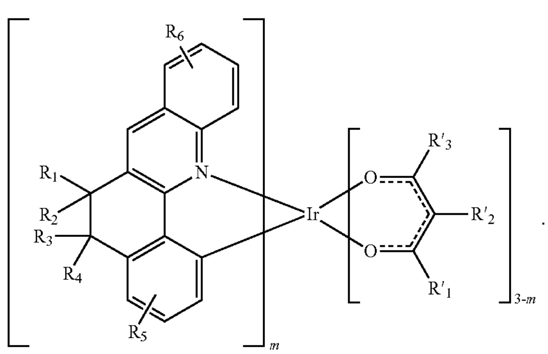
In another aspect, L_3 is



and R'_1, R'_2, and R'_3 are each independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof. Preferably, R'_2 is hydrogen. More preferably, at least one of R'_1, R'_2, and R'_3 contains a branched alkyl moiety with branching at a position further than the α position to the carbonyl group. Most preferably, at least one of R'_1 and R'_3 is isobutyl.

In one aspect, the compound has the formula:

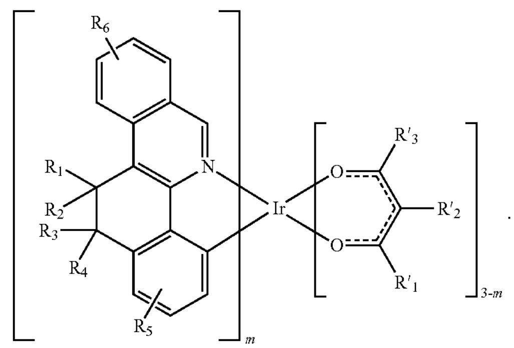
Formula III



R_5 and R_6 may represent mono, di, tri, or tetra substitutions. Each of R_5 and R_6 are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof. At least one of R_1, R_2, R_3, R_4, and R_6 is not hydrogen or deuterium. m is 1, 2, or 3.

In another aspect, the compound has the formula:

Formula IV



R_5 and R_6 may represent mono, di, tri, or tetra substitutions. Each of R_5 and R_6 are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof. At least one of R_1, R_2, R_3, R_4, and R_6 is not hydrogen or deuterium. m is 1, 2, or 3.

Generally, it is desirable to maintain red emission while improving other properties of these compounds, such as evaporation temperature and solubility. In some instances, it may be desirable for the compound to have a less bulky substituent on ring A. Ring A, e.g., benzene, may be substituted with hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, as discussed above. However, it is thought that placing a bulky substituent on ring A may cause a pronounced shift in the emission color of the compound. In some aspects, then, it is preferable to substitute ring A with less bulky chemical substituents to maintain good red emission while improving other properties of the compound, such as evaporation temperature and solubility.

In one aspect, the compound is homoleptic. In another aspect, the compound is heteroleptic.

Specific non-limiting examples of organometallic compounds comprising a phenylquinoline or phenylisoquinoline ligand having the quinoline or isoquinoline linked to the phenyl of the phenylquinoline or phenylisoquinoline, respectively, via a 2 carbon atom linker are provided. These compounds also comprise a bulky substituent on the quinoline, isoquinoline, or linker. In one aspect, the compound is selected from the group consisting of:

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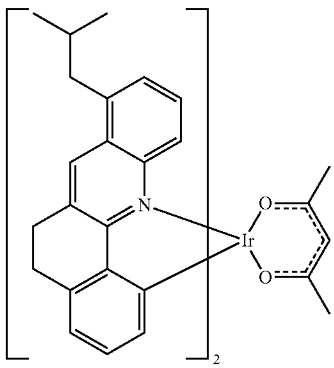

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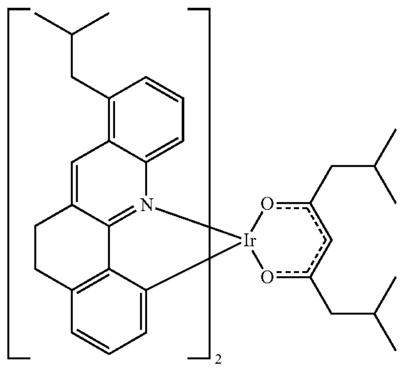

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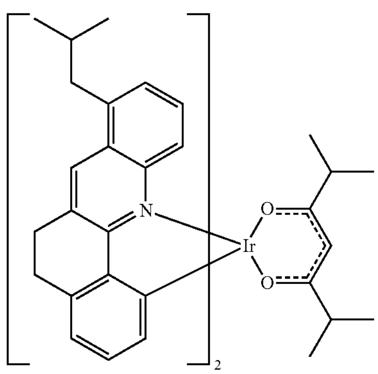

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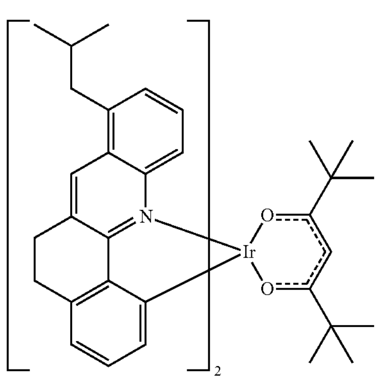

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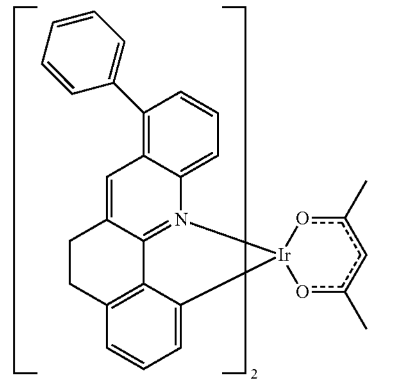

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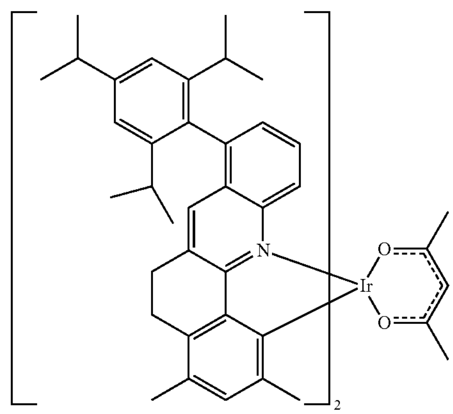

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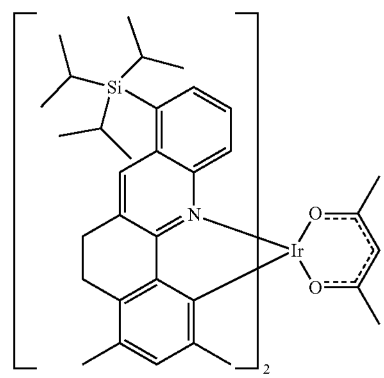

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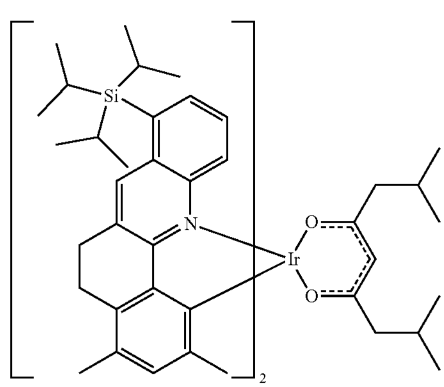

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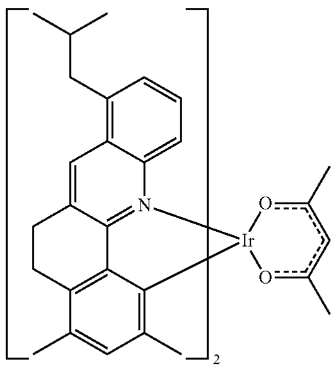

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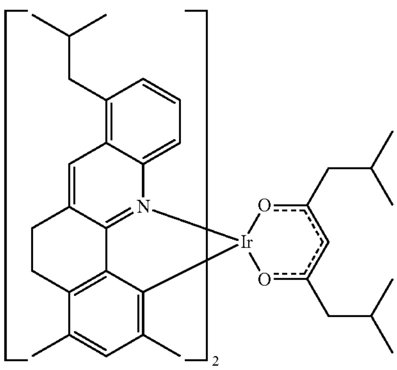

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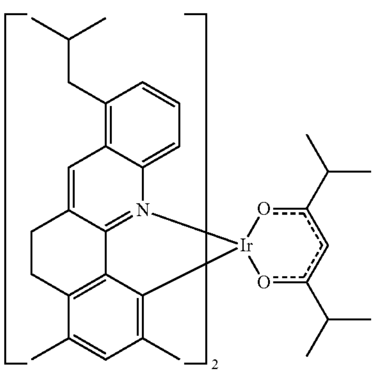

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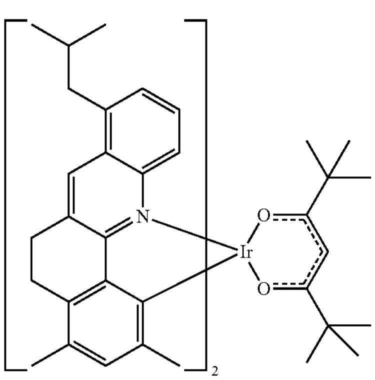

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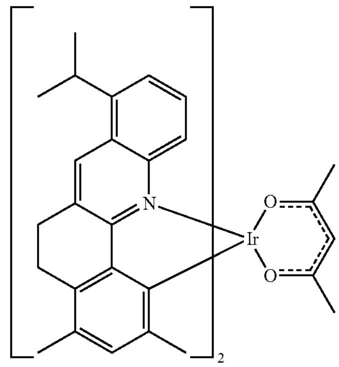

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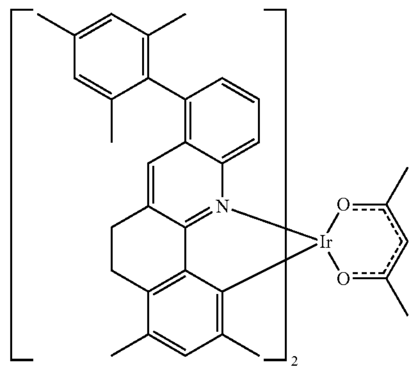

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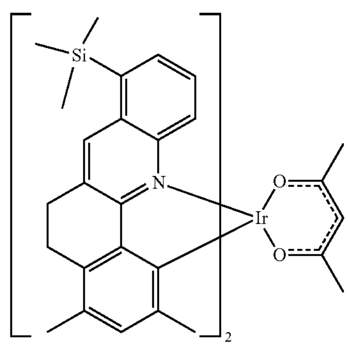

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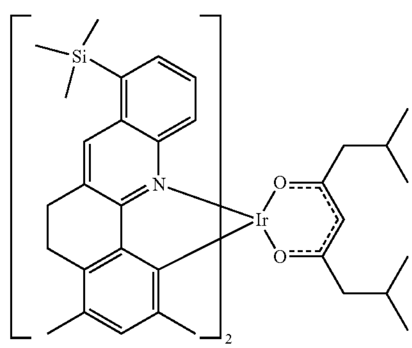

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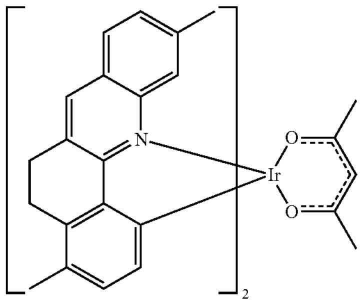

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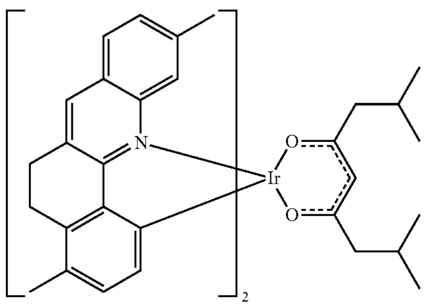

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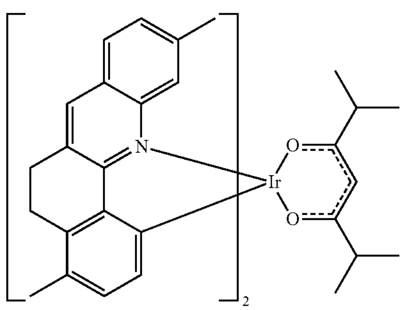

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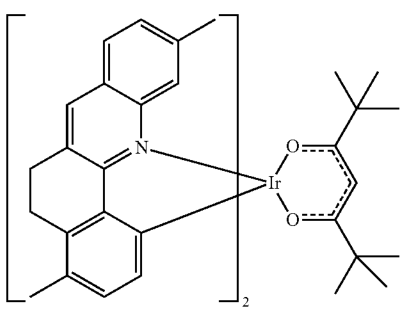

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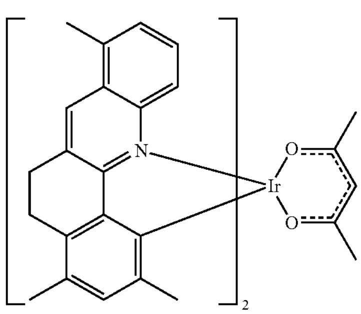

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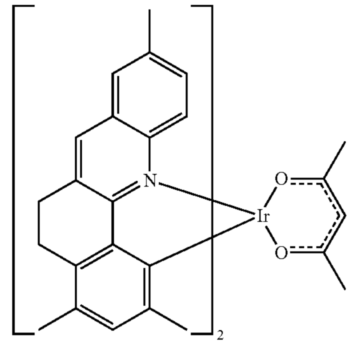

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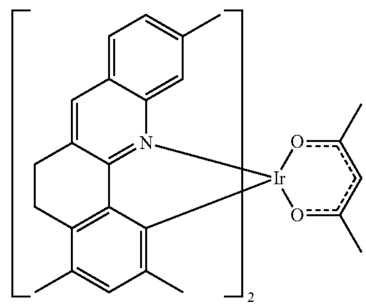

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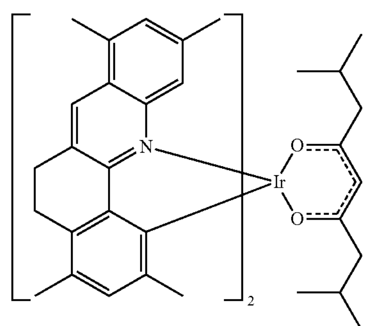

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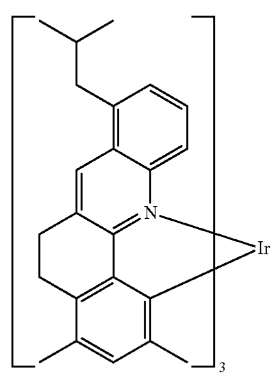

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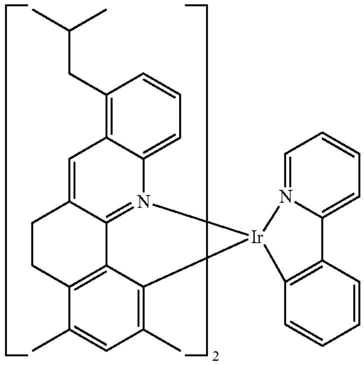

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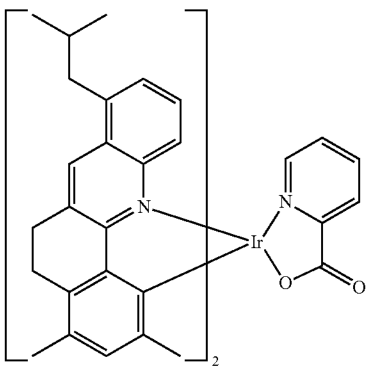

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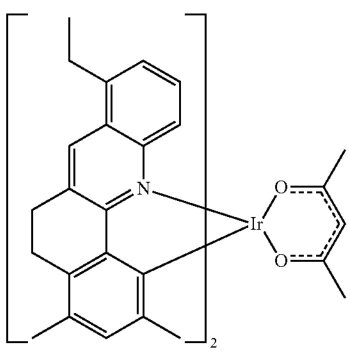

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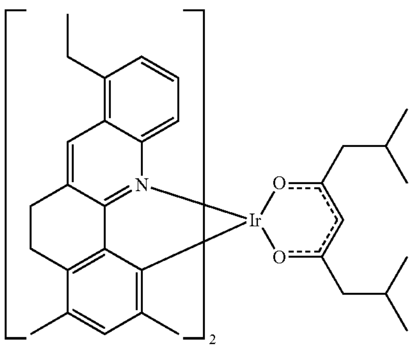

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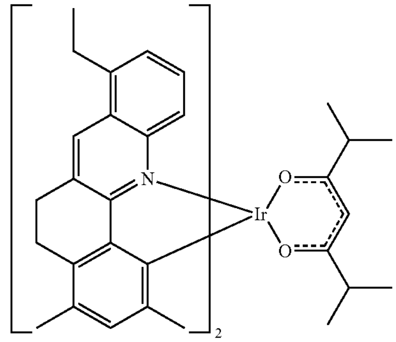

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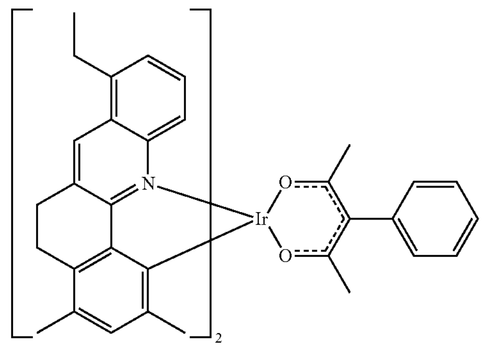

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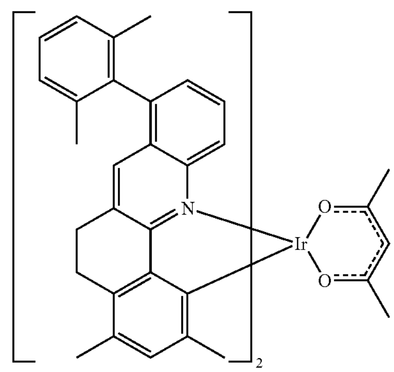

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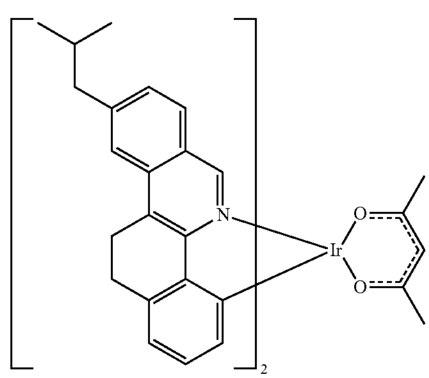

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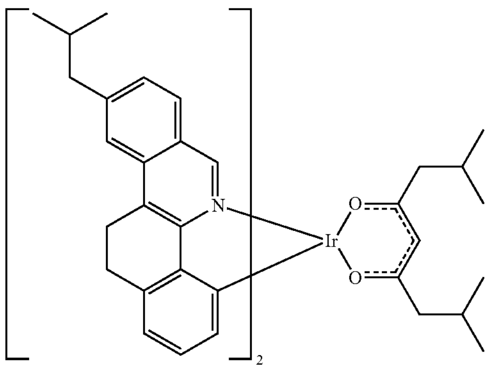

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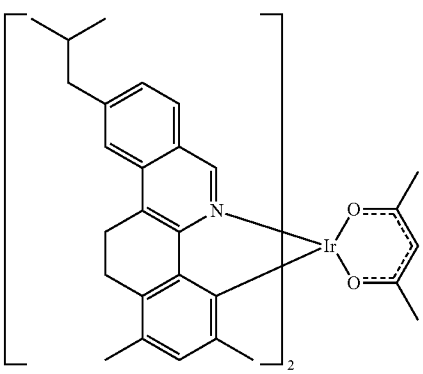

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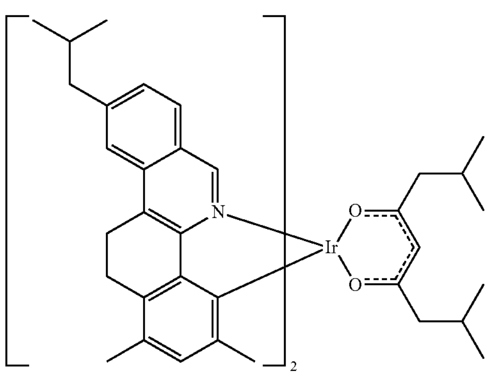

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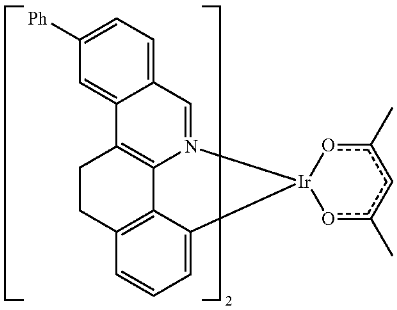

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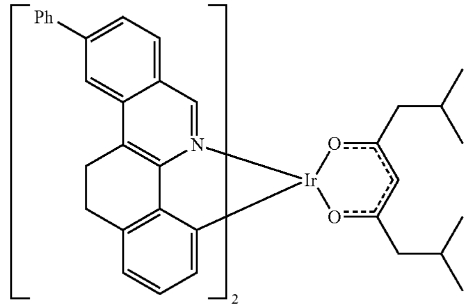

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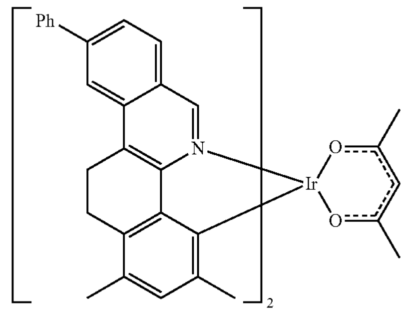

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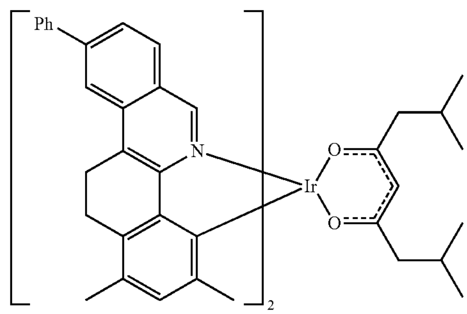

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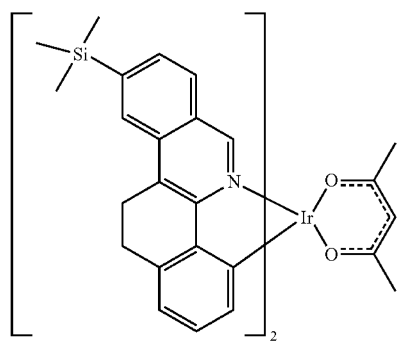

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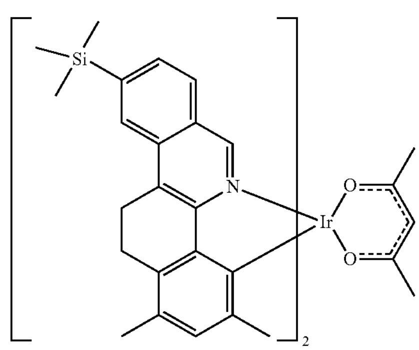

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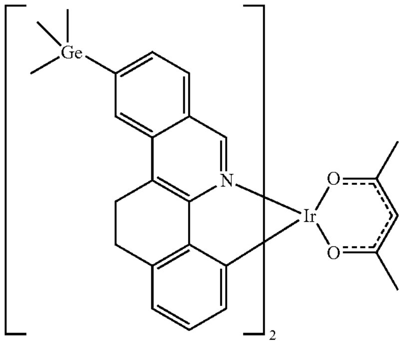

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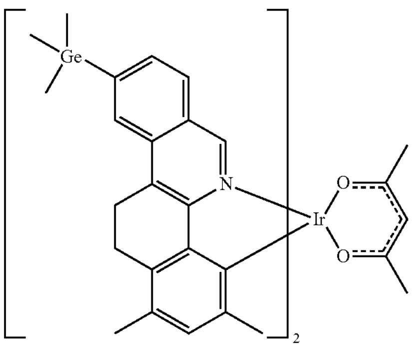

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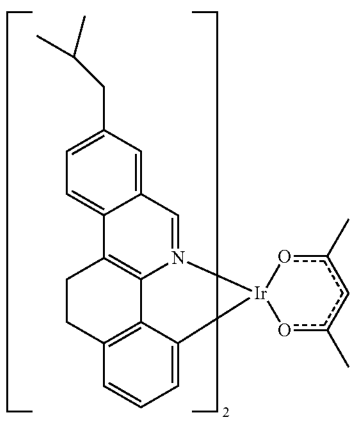

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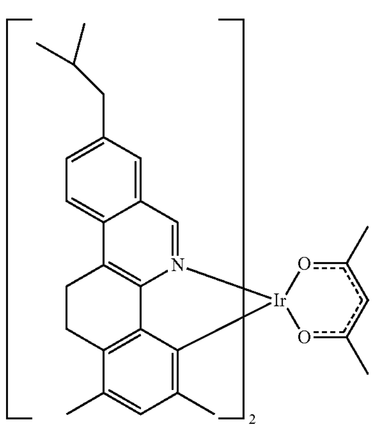

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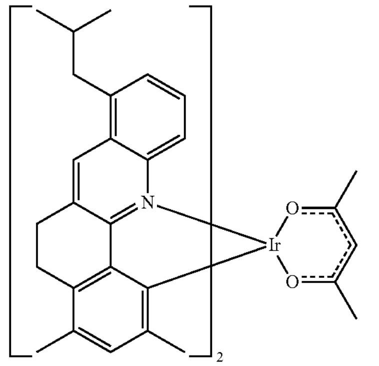
Preferably, the compound is:



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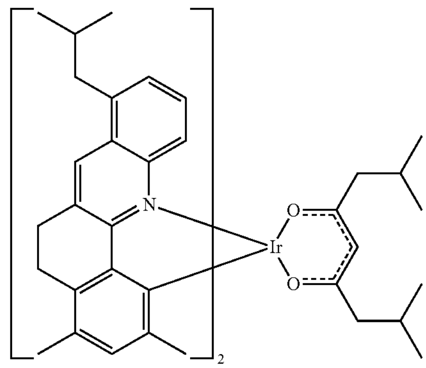
or



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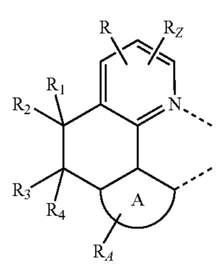
Additionally, a first device comprising a first organic light emitting device is provided. The organic light emitting device further comprises an anode, a cathode, and an organic layer, disposed between the anode and the cathode. The organic layer further comprises a compound having the formula $M(L_1)_x(L_2)_y(L_3)_z$.

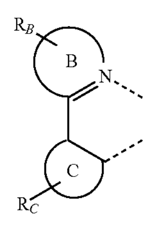
The ligand L_1 is

Formula I



The ligand L_2 is

Formula II



The ligand L_3 is a third ligand.

Each L_1, L_2 and L_3 can be the same or different. M is a metal having an atomic number greater than 40. x is 1, 2, or 3. y is 0, 1, or 2. z is 0, 1, or 2. x+y+z is the oxidation state of the metal M. R is a carbocyclic or heterocyclic ring fused to the pyridine ring. R is optionally further substituted with R'. A, B, and C are each independently a 5 or 6-membered carbocyclic or heterocyclic ring. R', R_Z, R_A, R_B, and R_C may represent mono, di, tri, or tetra substitutions. Each of R_1, R_2, R_3, R_4, R', R_Z, R_A, R_B, and R_C are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof. At least one of R_1, R_2, R_3, R_4, and R' is not hydrogen or deuterium. Any two adjacent R_1, R_2, R_3, R_4, and R' are optionally linked to form an alkyl ring.

The various specific aspects discussed above for compounds having the formula $M(L_1)_x(L_2)_y(L_3)_z$ are also applicable to a compound having $M(L_1)_x(L_2)_y(L_3)$, that is used in the first device. In particular, specific aspects of L_1, L_2, L_3, A, B, C, R_A, R_B, R_C, R_Z, R, R', R_1, R_2, R_3, R_4, R_5, R_6, R'_1, R'_2, R'_3, M, m Formula III and Formula IV of the compound having the formula $M(L_1)_x(L_2)_y(L_3)_z$, are also applicable to a compound having $M(L_1)_x(L_2)_y(L_3)_z$ that is used in the first device.

In one aspect, the first device is a consumer product. In another aspect, the first device is an organic light emitting device. In yet another aspect, the first device comprises a lighting panel.

In one aspect, the organic layer is an emissive layer and the compound is an emissive dopant. In another aspect, the organic layer further comprises a host. Preferably, the host is a metal 8-hydroxyquinolate.

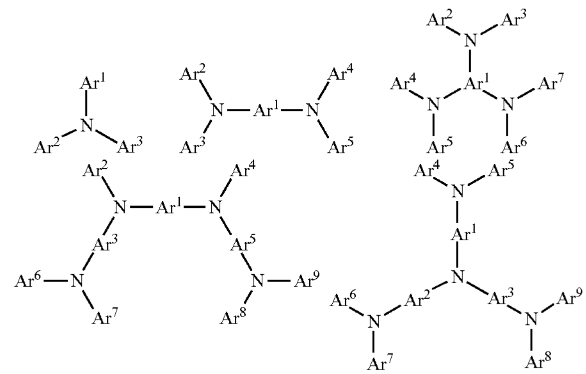
Combination with Other Materials

The materials described herein as useful for a particular layer in an organic light emitting device may be used in combination with a wide variety of other materials present in the device. For example, emissive dopants disclosed herein may be used in conjunction with a wide variety of hosts, transport layers, blocking layers, injection layers, electrodes and other layers that may be present. The materials described or referred to below are non-limiting examples of materials that may be useful in combination with the compounds disclosed herein, and one of skill in the art can readily consult the literature to identify other materials that may be useful in combination.

HIL/HTL:

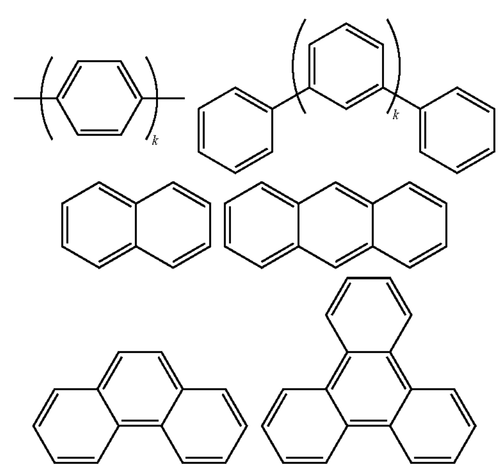
A hole injecting/transporting material to be used in the present invention is not particularly limited, and any compound may be used as long as the compound is typically used as a hole injecting/transporting material. Examples of the material include, but not limit to: a phthalocyanine or porphyrin derivative; an aromatic amine derivative; an indolocarbazole derivative; a polymer containing fluorohydrocarbon; a polymer with conductivity dopants; a conducting polymer, such as PEDOT/PSS; a self-assembly monomer derived from compounds such as phosphonic acid and silane derivatives; a metal oxide derivative, such as MoO_x; a p-type semiconducting organic compound, such as 1,4,5,8,9,12-Hexaazatriphenylenehexacarbonitrile; a metal complex, and a cross-linkable compounds.

Examples of aromatic amine derivatives used in HIL or HTL include, but not limit to the following general structures:



Each of Ar^1 to Ar^9 is selected from the group consisting aromatic hydrocarbon cyclic compounds such as benzene, biphenyl, triphenyl, triphenylene, naphthalene, anthracene, phenalene, phenanthrene, fluorene, pyrene, chrysene, perylene, azulene; group consisting aromatic heterocyclic compounds such as dibenzothiophene, dibenzofuran, dibenzoselenophene, furan, thiophene, benzofuran, benzothiophene, benzoselenophene, carbazole, indolocarbazole, pyridylindole, pyrrolodipyridine, pyrazole, imidazole, triazole, oxazole, thiazole, oxadiazole, oxatriazole, dioxazole, thiadiazole, pyridine, pyridazine, pyrimidine, pyrazine, triazine, oxazine, oxathiazine, oxadiazine, indole, benzimidazole, indazole, indoxazine, benzoxazole, benzisoxazole, benzothiazole, quinoline, isoquinoline, cinnoline, quinazoline, quinoxaline, naphthyridine, phthalazine, pteridine, xanthene, acridine, phenazine, phenothiazine, phenoxazine, benzofuropyridine, furodipyridine, benzothienopyridine, thienodipyridine, benzoselenophenopyridine, and selenophenodipyridine; and group consisting 2 to 10 cyclic structural units which are groups of the same type or different types selected from the aromatic hydrocarbon cyclic group and the aromatic heterocyclic group and are bonded to each other directly or via at least one of oxygen atom, nitrogen atom, sulfur atom, silicon atom, phosphorus atom, boron atom, chain structural unit and the aliphatic cyclic group. Wherein each Ar is further substituted by a substituent selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof.

In one aspect, Ar^1 to Ar^9 is independently selected from the group consisting of:



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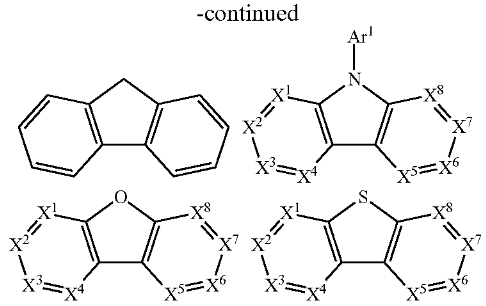
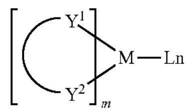


k is an integer from 1 to 20; X^1 to X^8 is C (including CH) or N; Ar^1 has the same group defined above.

Examples of metal complexes used in HIL or HTL include, but not limit to the following general formula:



M is a metal, having an atomic weight greater than 40; $(Y^1\text{-}Y^2)$ is a bidentate ligand, Y^1 and Y^2 are independently selected from C, N, O, P, and S; L is an ancillary ligand; m is an integer value from 1 to the maximum number of ligands that may be attached to the metal; and m+n is the maximum number of ligands that may be attached to the metal.

In one aspect, $(Y^1\text{-}Y^2)$ is a 2-phenylpyridine derivative.

In another aspect, $(Y^1\text{-}Y^2)$ is a carbene ligand.

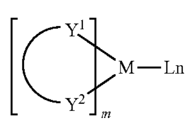
In another aspect, M is selected from Ir, Pt, Os, and Zn.

In a further aspect, the metal complex has a smallest oxidation potential in solution vs. Fc^+/Fc couple less than about 0.6 V.

Host:

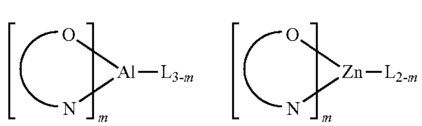
The light emitting layer of the organic EL device of the present invention preferably contains at least a metal complex as light emitting material, and may contain a host material using the metal complex as a dopant material. Examples of the host material are not particularly limited, and any metal complexes or organic compounds may be used as long as the triplet energy of the host is larger than that of the dopant.

Examples of metal complexes used as host are preferred to have the following general formula:



M is a metal; $(Y^3\text{-}Y^4)$ is a bidentate ligand, Y^3 and Y^4 are independently selected from C, N, O, P, and S; L is an ancillary ligand; m is an integer value from 1 to the maximum number of ligands that may be attached to the metal; and m+n is the maximum number of ligands that may be attached to the metal.

In one aspect, the metal complexes are:



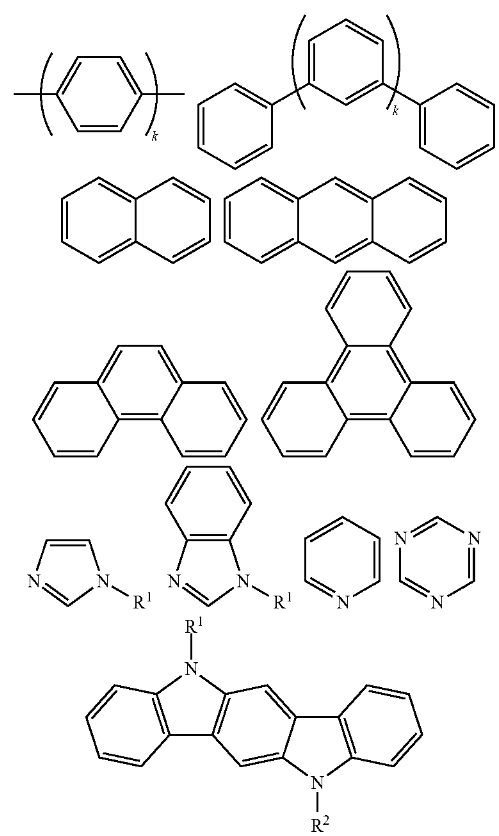
(O—N) is a bidentate ligand, having metal coordinated to atoms O and N.

In another aspect, M is selected from Ir and Pt.

In a further aspect, $(Y^3\text{-}Y^4)$ is a carbene ligand.

Examples of organic compounds used as host are selected from the group consisting aromatic hydrocarbon cyclic compounds such as benzene, biphenyl, triphenyl, triphenylene, naphthalene, anthracene, phenalene, phenanthrene, fluorene, pyrene, chrysene, perylene, azulene; group consisting aromatic heterocyclic compounds such as dibenzothiophene, dibenzofuran, dibenzoselenophene, furan, thiophene, benzofuran, benzothiophene, benzoselenophene, carbazole, indolocarbazole, pyridylindole, pyrrolodipyridine, pyrazole, imidazole, triazole, oxazole, thiazole, oxadiazole, oxatriazole, dioxazole, thiadiazole, pyridine, pyridazine, pyrimidine, pyrazine, triazine, oxazine, oxathiazine, oxadiazine, indole, benzimidazole, indazole, indoxazine, benzoxazole, benzisoxazole, benzothiazole, quinoline, isoquinoline, cinnoline, quinazoline, quinoxaline, naphthyridine, phthalazine, pteridine, xanthene, acridine, phenazine, phenothiazine, phenoxazine, benzofuropyridine, furodipyridine, benzothienopyridine, thienodipyridine, benzoselenophenopyridine, and selenophenodipyridine; and group consisting 2 to 10 cyclic structural units which are groups of the same type or different types selected from the aromatic hydrocarbon cyclic group and the aromatic heterocyclic group and are bonded to each other directly or via at least one of oxygen atom, nitrogen atom, sulfur atom, silicon atom, phosphorus atom, boron atom, chain structural unit and the aliphatic cyclic group. Wherein each group is further substituted by a substituent selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof.

In one aspect, host compound contains at least one of the following groups in the molecule:



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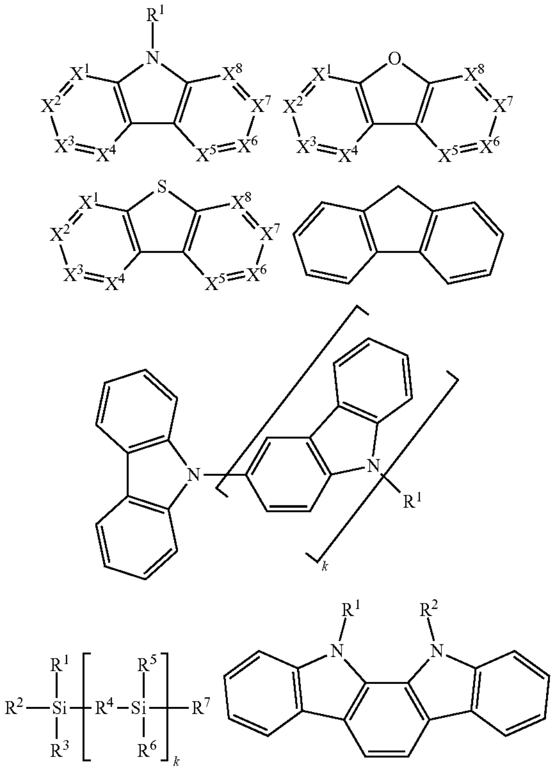


R^1 to R^7 is independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, when it is aryl or heteroaryl, it has the similar definition as Ar's mentioned above.

k is an integer from 0 to 20.

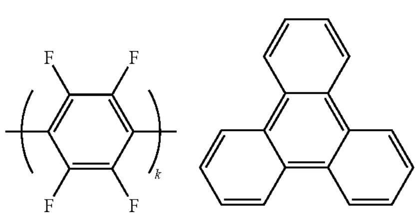
X^1 to X^8 is selected from C (including CH) or N.

HBL:

A hole blocking layer (HBL) may be used to reduce the number of holes and/or excitons that leave the emissive layer. The presence of such a blocking layer in a device may result in substantially higher efficiencies as compared to a similar device lacking a blocking layer. Also, a blocking layer may be used to confine emission to a desired region of an OLED.

In one aspect, compound used in HBL contains the same molecule used as host described above.

In another aspect, compound used in HBL contains at least one of the following groups in the molecule:



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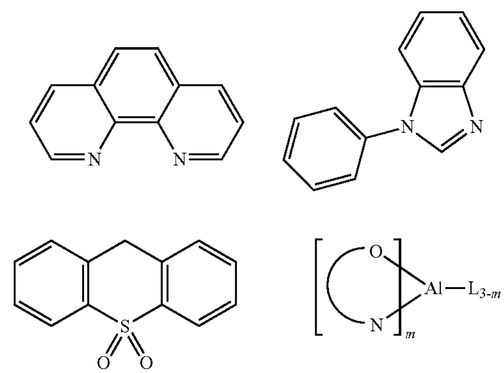
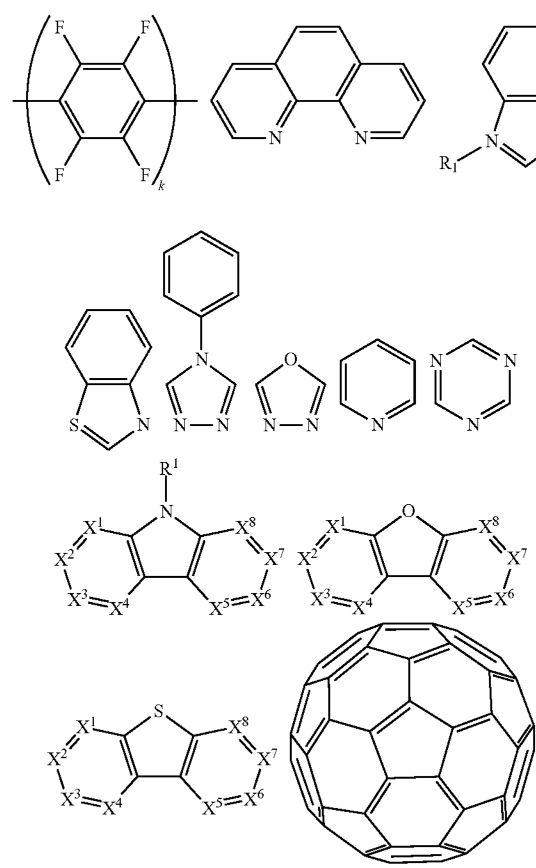


k is an integer from 0 to 20; L is an ancillary ligand, m is an integer from 1 to 3.

ETL:

Electron transport layer (ETL) may include a material capable of transporting electrons. Electron transport layer may be intrinsic (undoped), or doped. Doping may be used to enhance conductivity. Examples of the ETL material are not particularly limited, and any metal complexes or organic compounds may be used as long as they are typically used to transport electrons.

In one aspect, compound used in ETL contains at least one of the following groups in the molecule:



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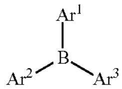


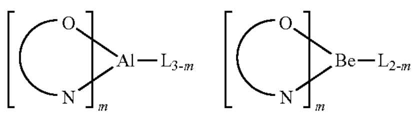
R^1 is selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, when it is aryl or heteroaryl, it has the similar definition as Ar's mentioned above.

Ar^1 to Ar^3 has the similar definition as Ar's mentioned above.

k is an integer from 0 to 20.

X^1 to X^8 is selected from C (including CH) or N.

In another aspect, the metal complexes used in ETL contains, but not limit to the following general formula:



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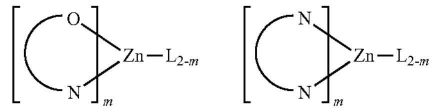


(O—N) or (N—N) is a bidentate ligand, having metal coordinated to atoms O, N or N, N; L is an ancillary ligand; m is an integer value from 1 to the maximum number of ligands that may be attached to the metal.

In any above-mentioned compounds used in each layer of the OLED device, the hydrogen atoms can be partially or fully deuterated.

In addition to and/or in combination with the materials disclosed herein, many hole injection materials, hole transporting materials, host materials, dopant materials, exiton/hole blocking layer materials, electron transporting and electron injecting materials may be used in an OLED. Non-limiting examples of the materials that may be used in an OLED in combination with materials disclosed herein are listed in Table 1 below. Table 1 lists non-limiting classes of materials, non-limiting examples of compounds for each class, and references that disclose the materials.

TABLE 1

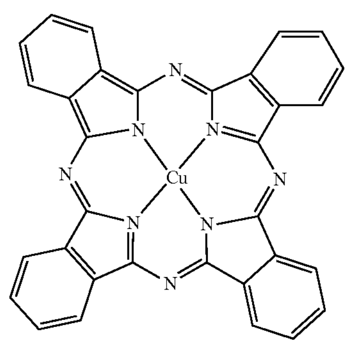
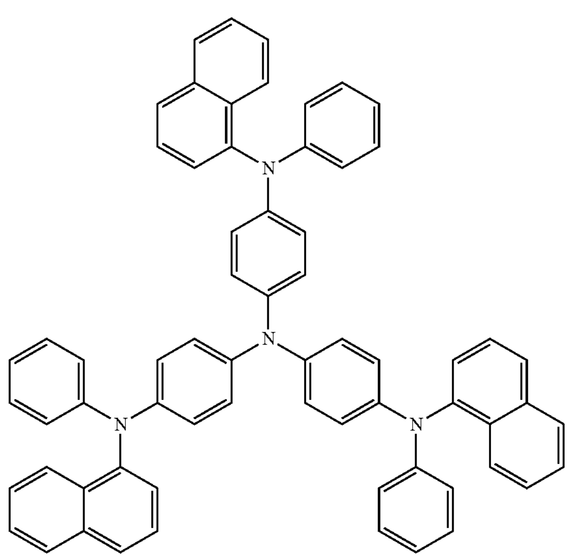
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Hole injection materials		
Phthalocyanine and porphryin compounds		Appl. Phys. Lett. 69, 2160 (1996)
Starburst triarylamines		J. Lumin. 72-74, 985 (1997)

TABLE 1-continued

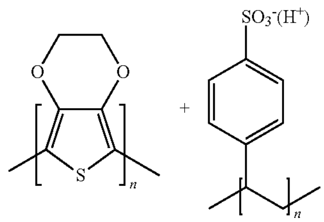
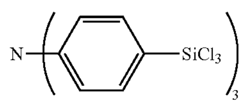
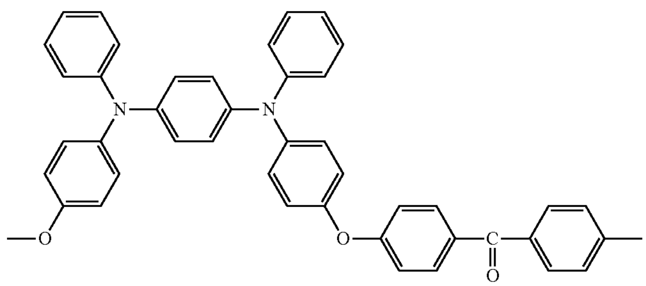
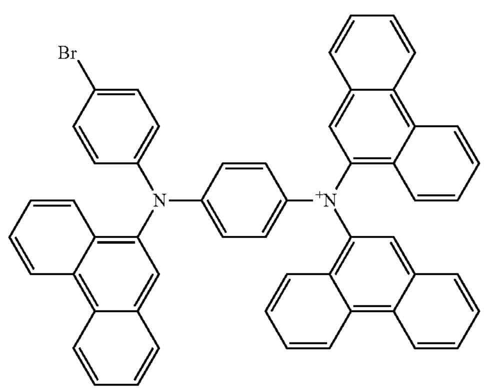
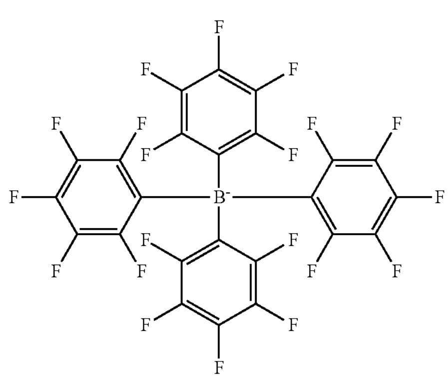
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
CF_x Fluorohydrocarbon polymer	$-[CH_xF_y]_n-$	Appl. Phys. Lett. 78, 673 (2001)
Conducting polymers (e.g., PEDOT:PSS, polyaniline, polypthiophene)		Synth. Met. 87, 171 (1997) WO2007002683
Phosphonic acid and sliane SAMs		US20030162053
Triarylamine or polythiophene polymers with conductivity dopants	 and  	EP1725079A1

TABLE 1-continued

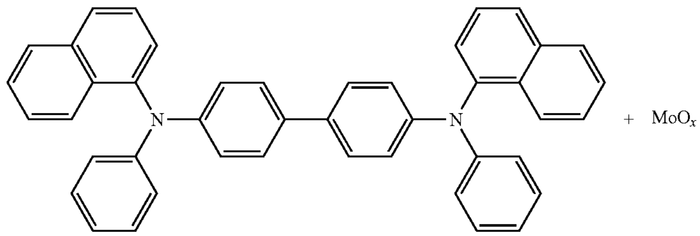
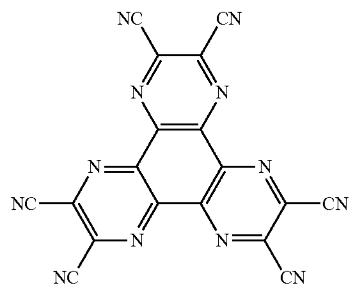
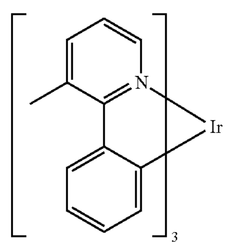
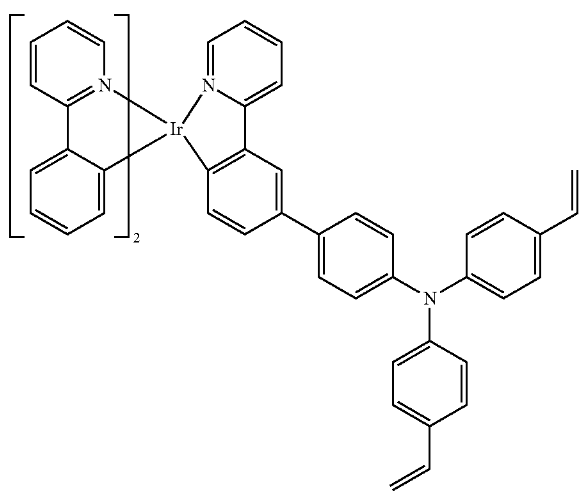
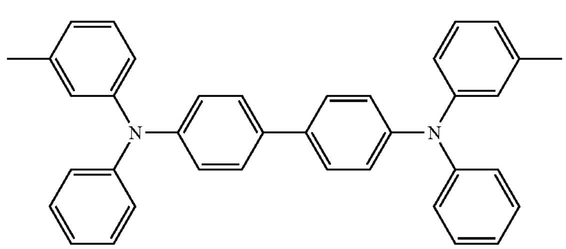
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Arylamines complexed with metal oxides such as molybdenum and tungsten oxides		SID Symposium Digest, 37, 923 (2006) WO2009018009
p-type semiconducting organic complexes		US20020158242
Metal organometallic complexes		US20060240279
Cross-linkable compounds		US20080220265
Hole transporting materials		
Triarylamines (e.g., TPD, α-NPD)		Appl. Phys. Lett. 51, 913 (1987)

TABLE 1-continued

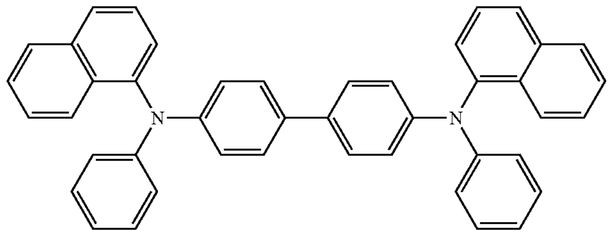
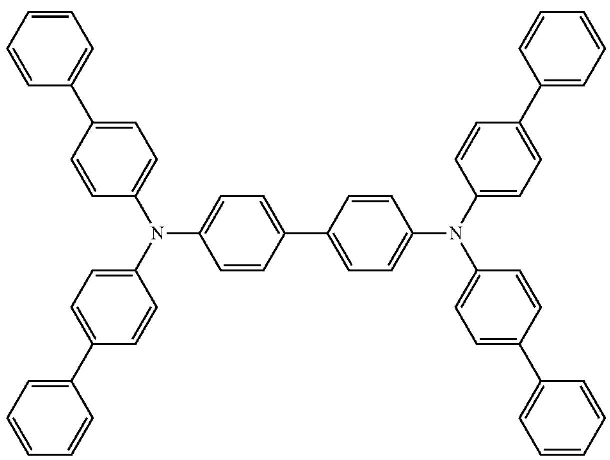
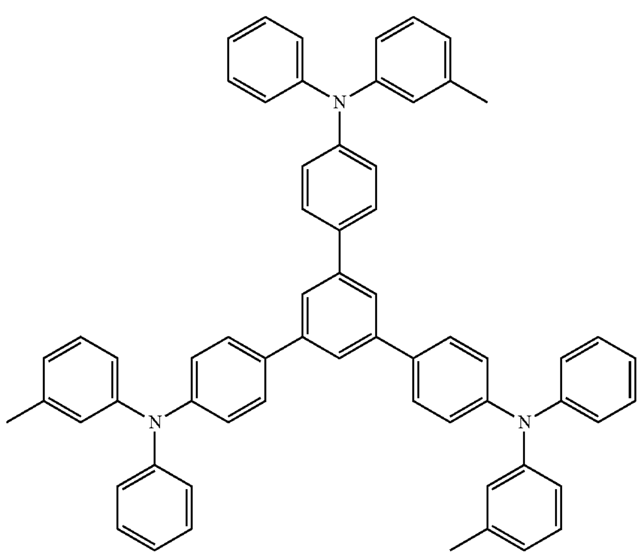
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		U.S. Pat. No. 5,061,569
		EP650955
		J. Mater. Chem. 3, 319 (1993)

TABLE 1-continued

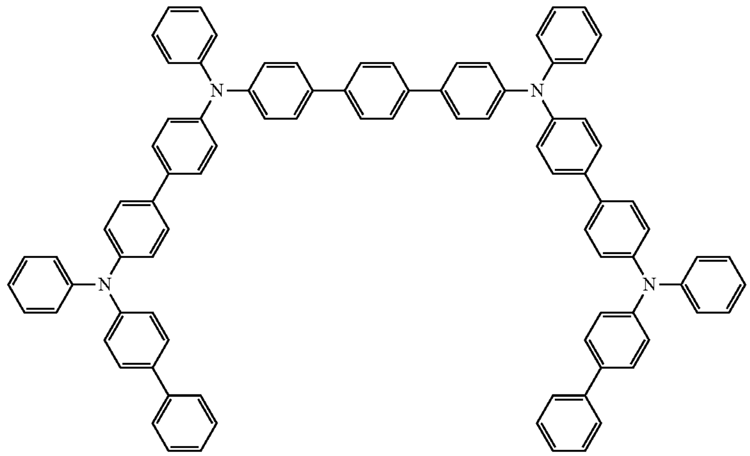
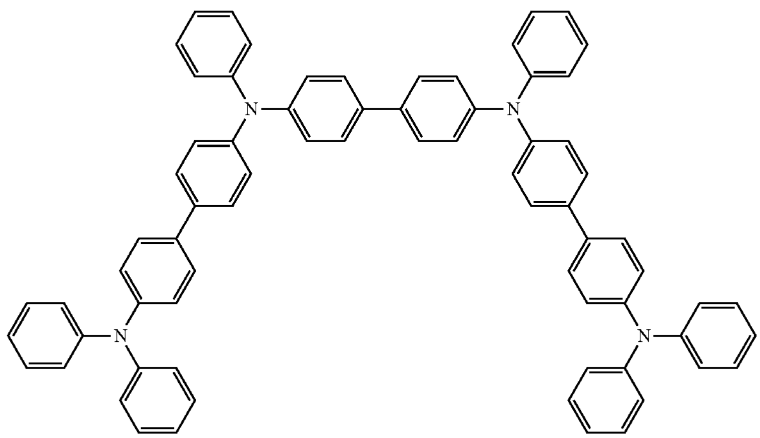
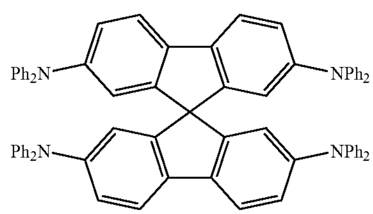
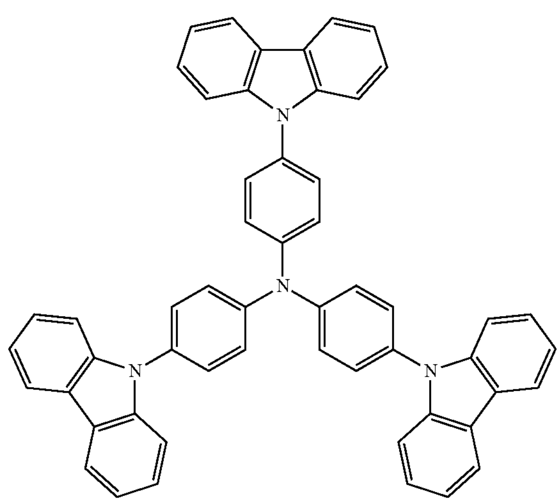
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		Appl. Phys. Lett. 90, 183503 (2007)
		Appl. Phys. Lett. 90, 183503 (2007)
Triaylamine on spirofluorene core		Synth. Met. 91, 209 (1997)
Arylamine carbazole compounds		Adv. Mater. 6, 677 (1994), US20080124572

TABLE 1-continued

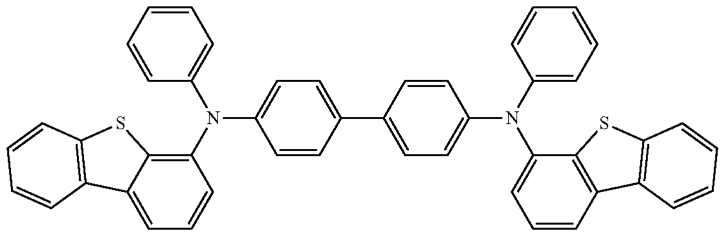
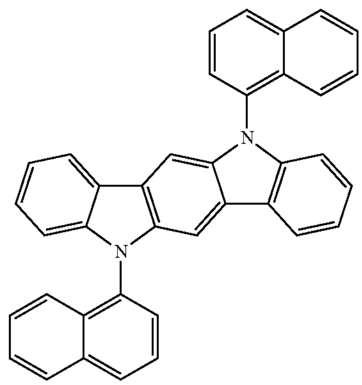
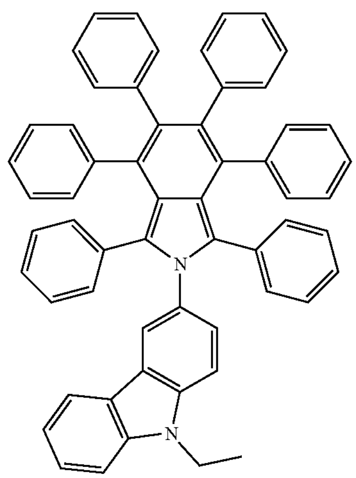
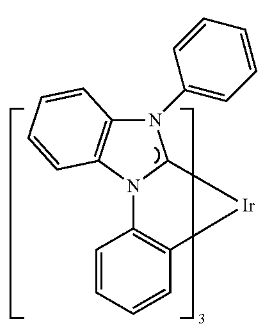
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Triarylamine with (di)benzothiophene/ (di)benzofuran		US20070278938, US20080106190
Indolocarbazoles		Synth. Met. 111, 421 (2000)
Isoindole compounds		Chem. Mater. 15, 3148 (2003)
Metal carbene complexes		US20080018221

TABLE 1-continued

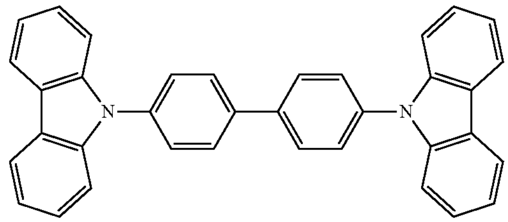
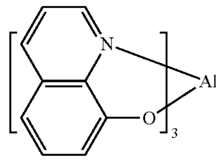
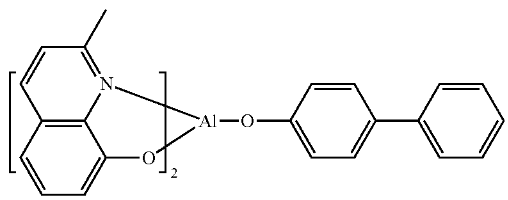
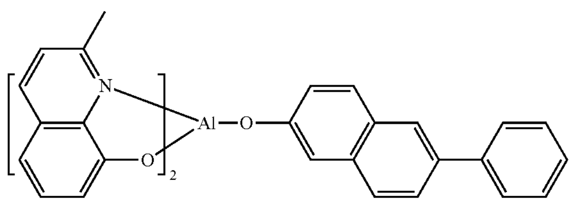
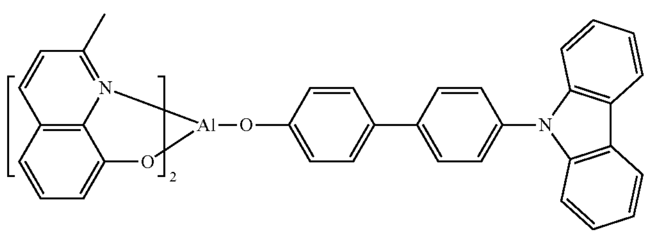
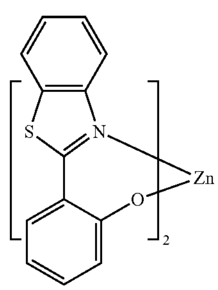
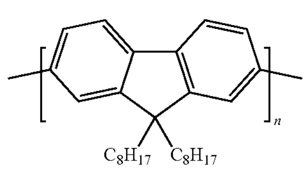
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Phosphorescent OLED host materials Red hosts		
Arylcarbazoles		Appl. Phys. Lett. 78, 1622 (2001)
Metal 8-hydroxyquinolates (e.g., Alq_3, BAlq)		Nature 395, 151 (1998)
		US20060202194
		WO2005014551
		WO2006072002
Metal phenoxybenzothiazole compounds		Appl. Phys. Lett. 90, 123509 (2007)
Conjugated oligomers and polymers (e.g., polyfluorene)		Org. Electron. 1, 15 (2000)

TABLE 1-continued

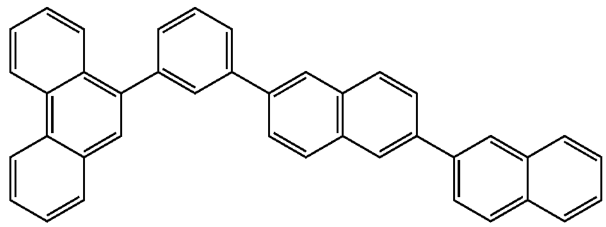
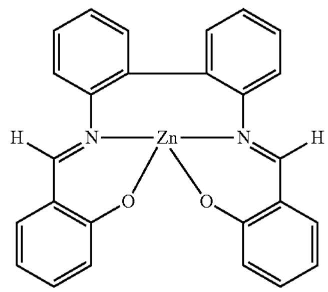
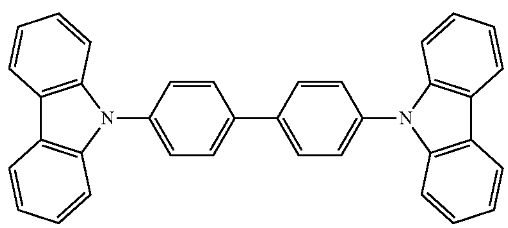
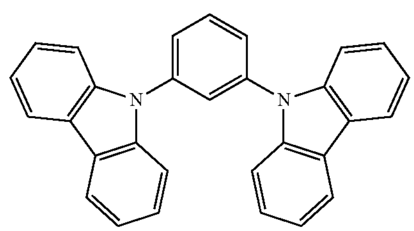
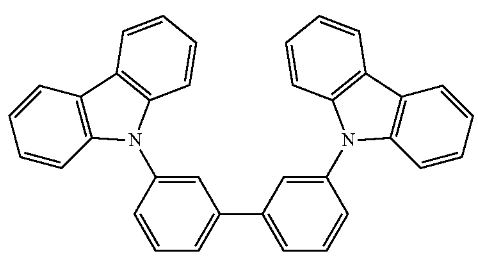
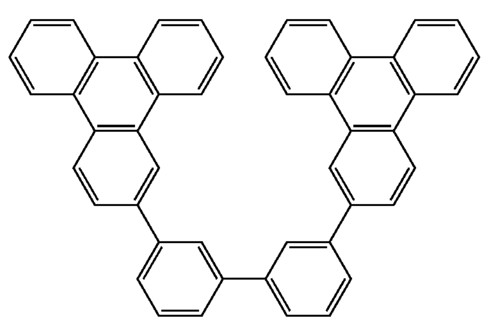
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Aromatic fused rings		WO2009066779, WO2009066778, WO2009063833, US20090045731, US20090045730, WO2009008311, US20090008605, US20090009065
Zinc complexes		WO2009062578
Green hosts		
Arylcarbazoles		Appl. Phys. Lett. 78, 1622 (2001)
		US20030175553
		WO2001039234
Aryltriphenylene compounds		US20060280965

TABLE 1-continued

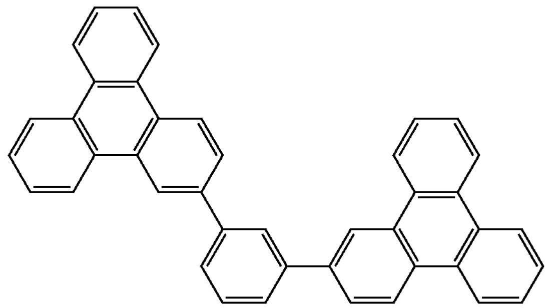
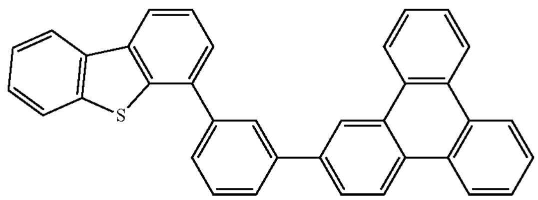
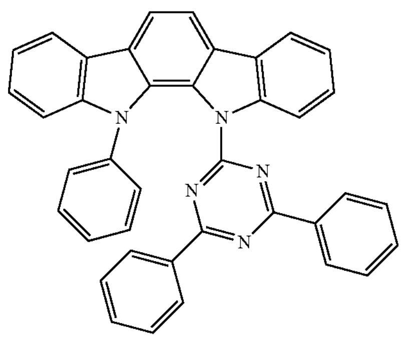
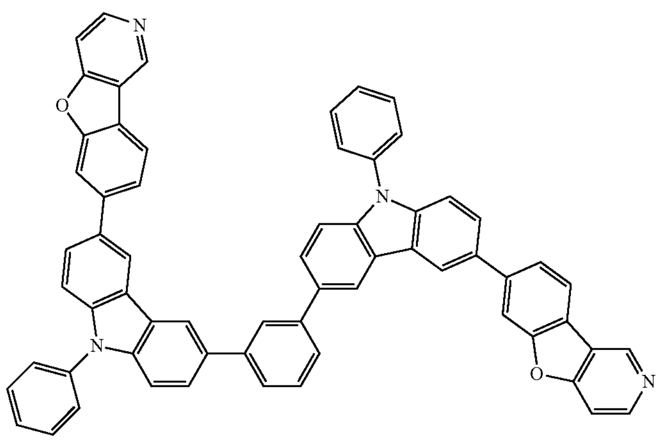
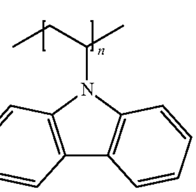
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US20060280965
		WO2009021126
Donor acceptor type molecules		WO2008056746
Aza-carbazole/DBT/DBF		JP2008074939
Polymers (e.g., PVK)		Appl. Phys. Lett. 77, 2280 (2000)

TABLE 1-continued

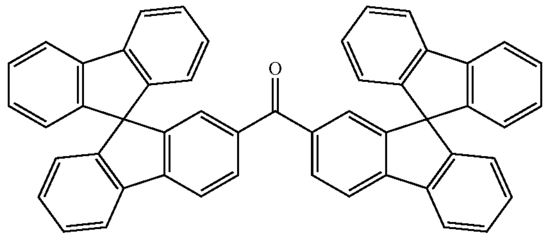
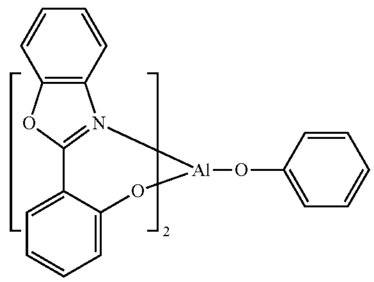
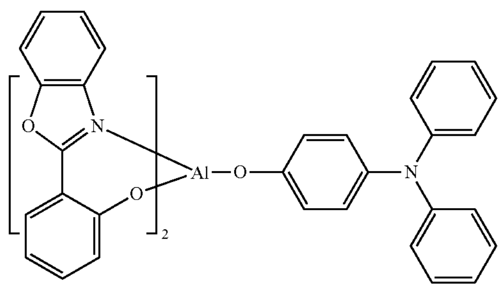
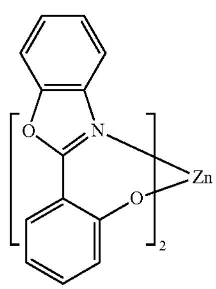
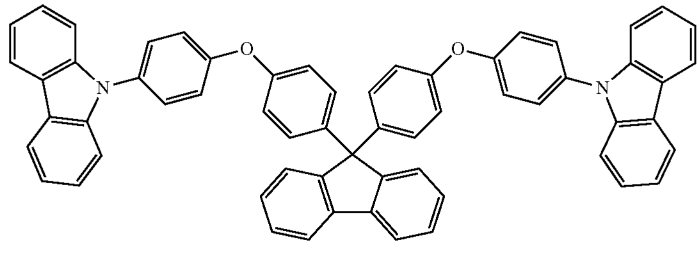
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Spirofluorene compounds		WO2004093207
Metal phenoxybenzooxazole compounds		WO2005089025
		WO2006132173
		JP200511610
Spirofluorene-carbazole compounds		JP2007254297

TABLE 1-continued

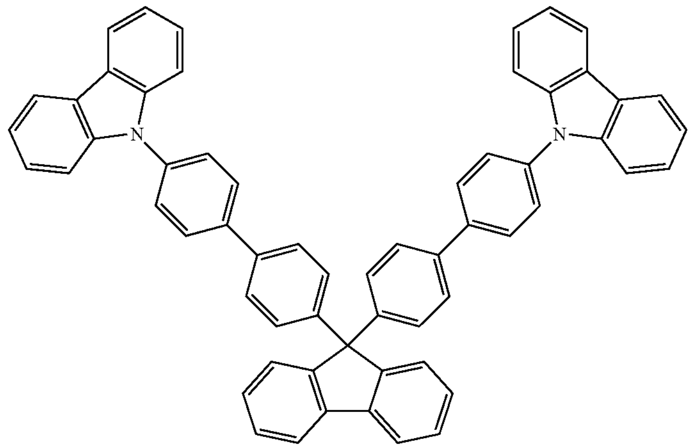
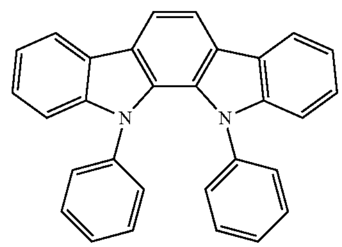
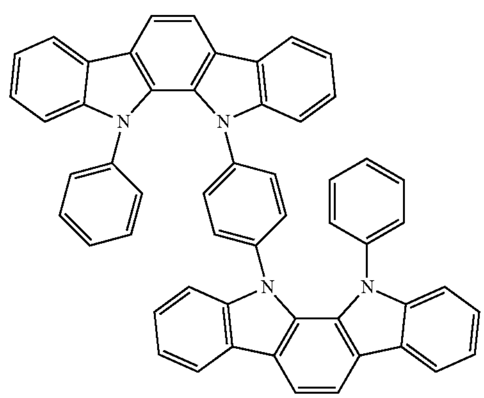
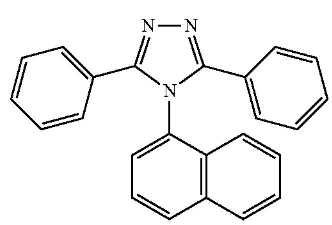
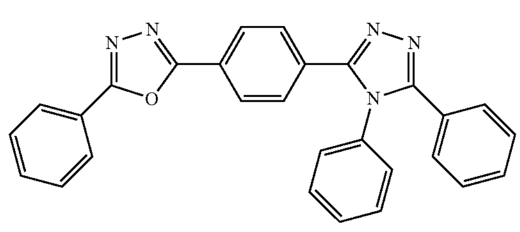
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		JP2007254297
Indolocabazoles		WO2007063796
		WO2007063754
5-member ring electron deficient heterocycles (e.g., triazole, oxadiazole)		J. Appl. Phys. 90, 5048 (2001)
		WO2004107822

TABLE 1-continued

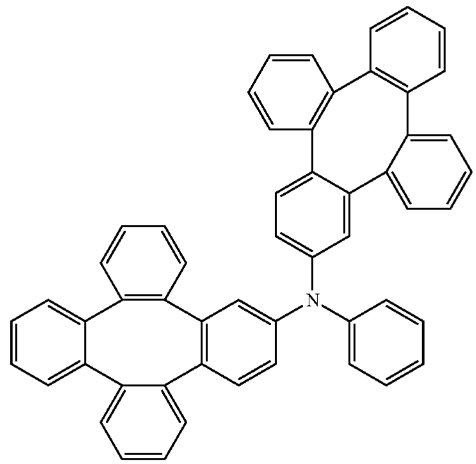
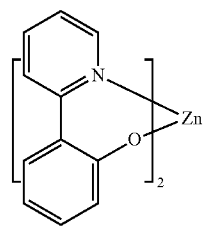
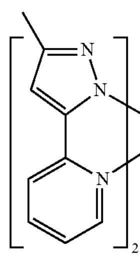
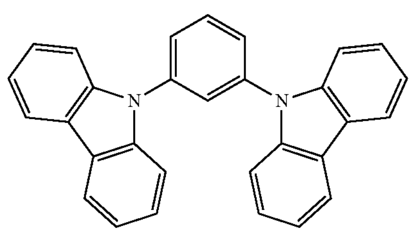
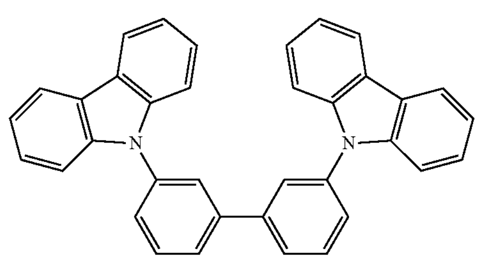
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Tetraphenylene complexes		US20050112407
Metal phenoxypyridine compounds		WO2005030900
Metal coordination complexes (e.g., Zn, Al with N^N ligands)		US20040137268, US20040137267
Blue hosts		
Arylcarbazoles		Appl. Phys. Lett, 82, 2422 (2003)
		US20070190359

TABLE 1-continued

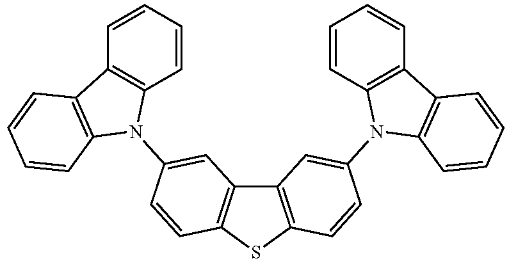
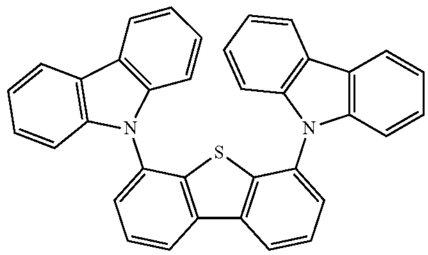
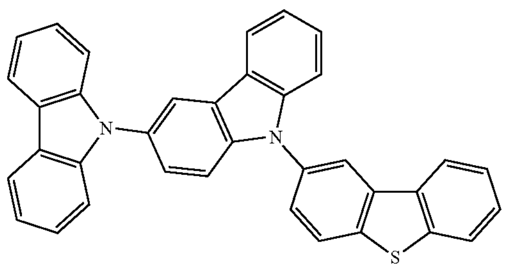
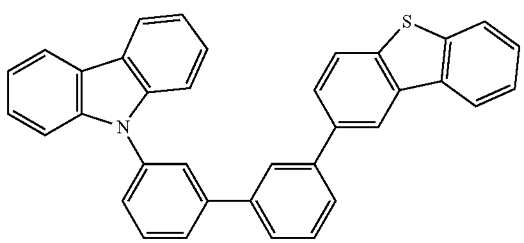
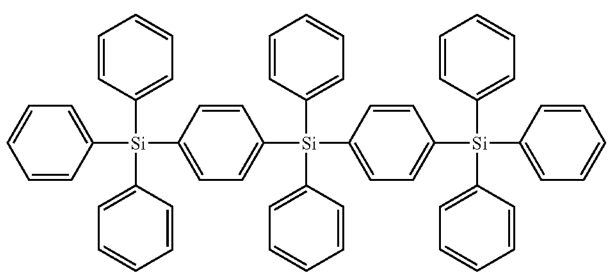
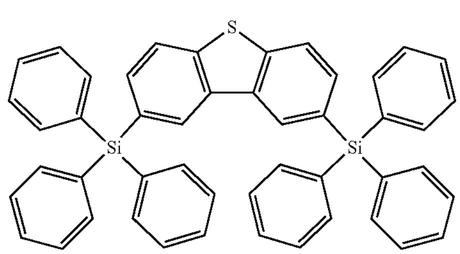
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Dibenzothiophene/ Dibenzofuran-carbazole compounds		WO2006114966, US20090167162
		US20090167162
		WO2009086028
		US20090030202, US20090017330
Silicon aryl compounds		US20050238919
		WO2009003898

TABLE 1-continued

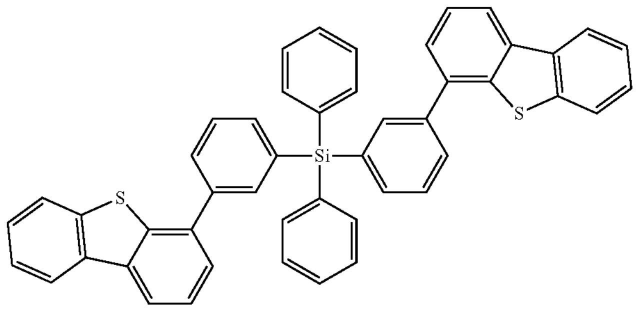
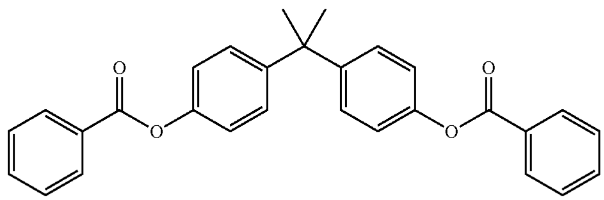
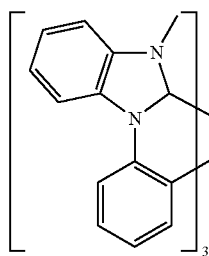
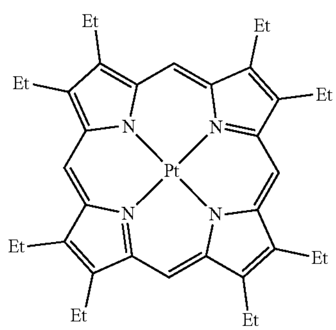
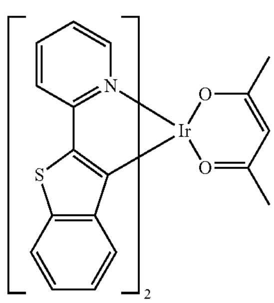
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Silicon/Germanium aryl compounds		EP2034538A
Aryl benzoyl ester		WO2006100298
High triplet metal organometallic complex		U.S. Pat. No. 7,154,114
Phosphorescent dopants Red dopants		
Heavy metal porphyrins (e.g., PtOEP)		Nature 395, 151 (1998)
Iridium (III) organometallic complexes		Appl. Phys. Lett. 78, 1622 (2001)

TABLE 1-continued

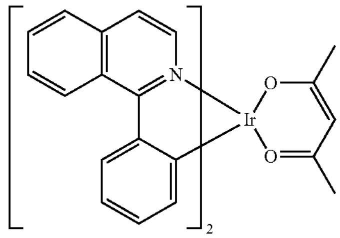
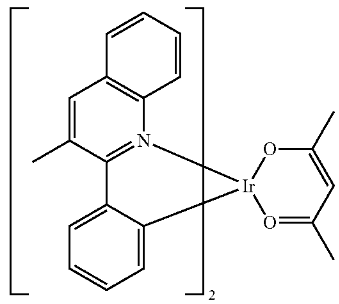
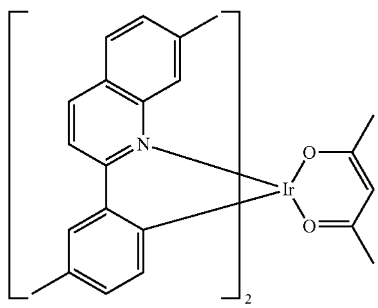
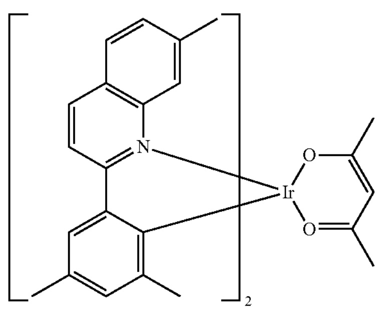
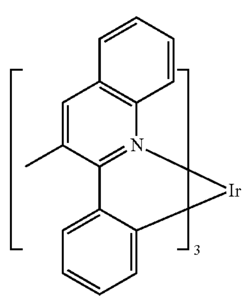
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US2006835469
		US2006835469
		US20060202194
		US20060202194
		US20070087321

TABLE 1-continued

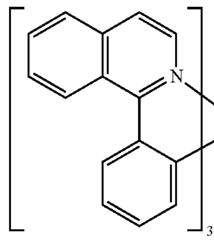
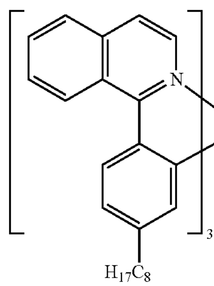
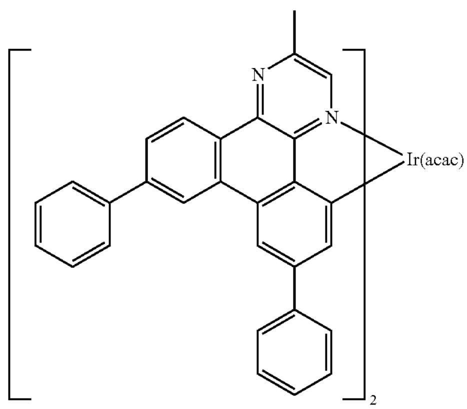
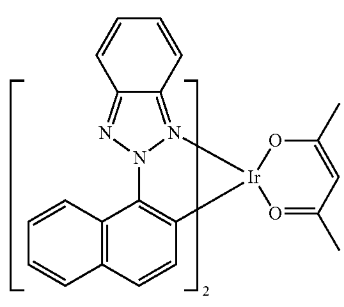
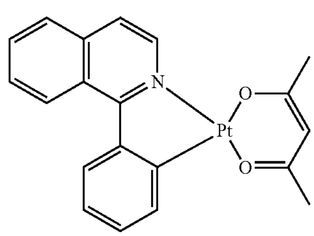
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US20070087321
		Adv. Mater. 19, 739 (2007)
		WO2009100991
		WO2008101842
Platinum (II) organometallic complexes		WO2003040257

TABLE 1-continued

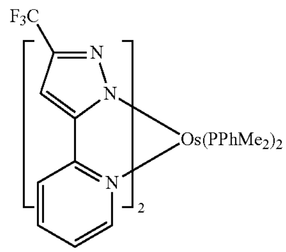
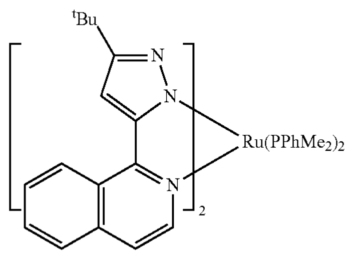
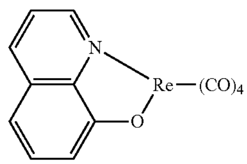
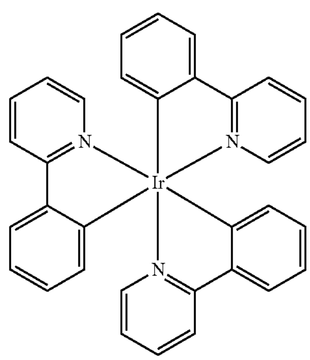
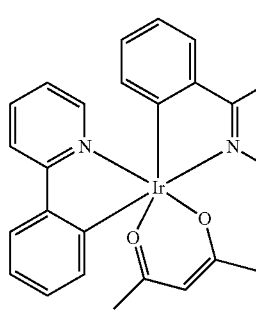
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Osminum (III) complexes		Chem. Mater. 17, 3532 (2005)
Ruthenium (II) complexes		Adv. Mater. 17, 1059 (2005)
Rhenium (I), (II), and (III) complexes		US20050244673
Green dopants		
Iridium (III) organometallic complexes	 and its derivatives	Inorg. Chem. 40, 1704 (2001)
		US20020034656

TABLE 1-continued

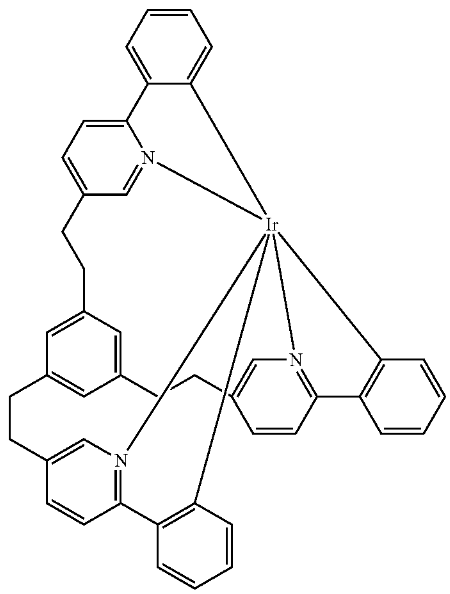
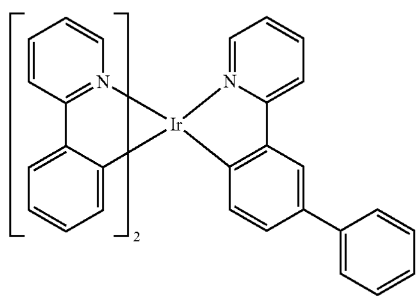
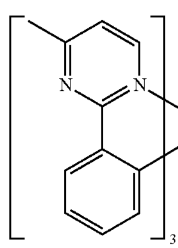
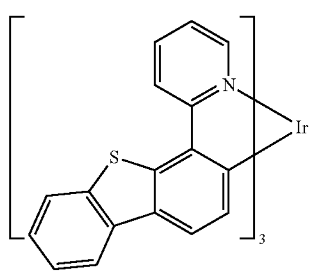
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		U.S. Pat. No. 7,332,232
		US20090108737
		US20090039776
		U.S. Pat. No. 6,921,915

TABLE 1-continued

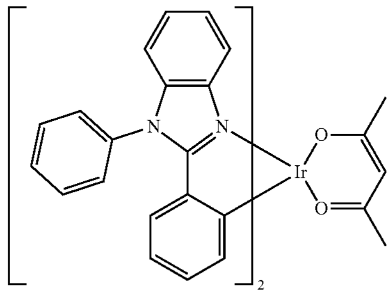
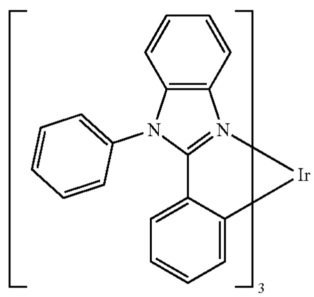
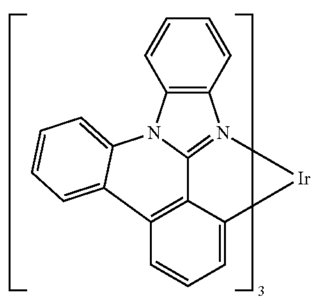
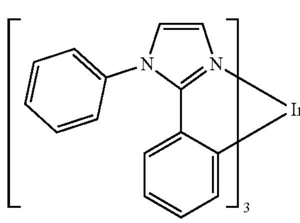
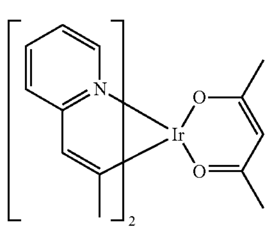
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		U.S. Pat. No. 6,687,266
		Chem. Mater. 16, 2480 (2004)
		US20070190359
		US 20060008670 JP2007123392
		Adv. Mater. 16, 2003 (2004)

TABLE 1-continued

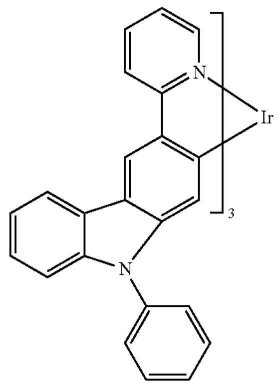
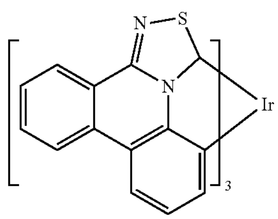
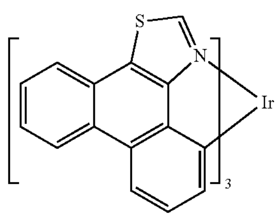
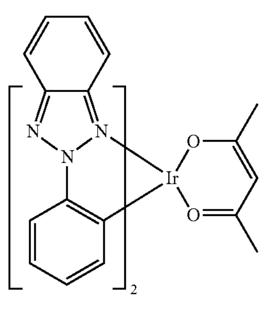
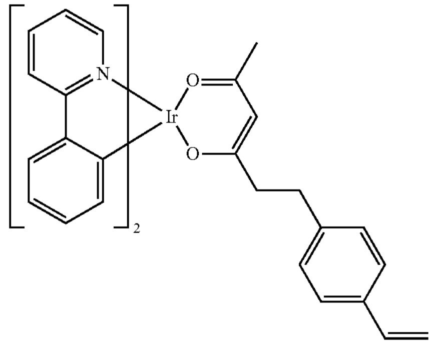
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		Angew. Chem. Int. Ed. 2006, 45, 7800
		WO2009050290
		US20090165846
		US20080015355
Monomer for polymeric metal organometallic compounds		U.S. Pat. No. 7,250,226 U.S. Pat. No. 7,396,598

TABLE 1-continued

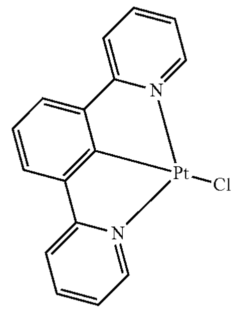
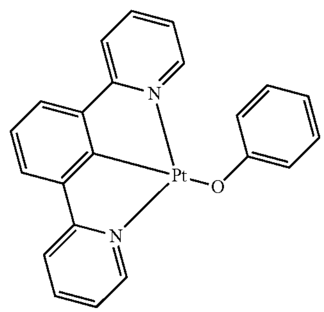
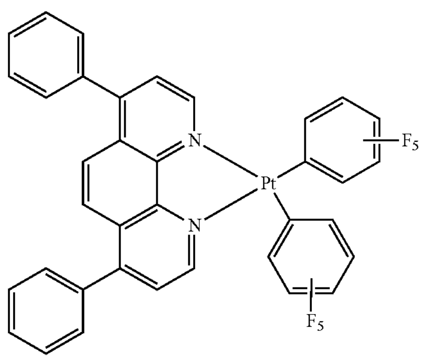
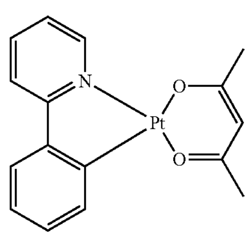
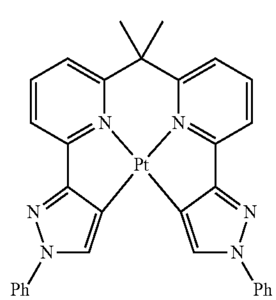
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Pt (II) organometallic complexes, including polydentated ligands		Appl. Phys. Lett. 86, 153505 (2005)
		Appl. Phys. Lett. 86, 153505 (2005)
		Chem. Lett. 34, 592 (2005)
		WO2002015645
		US20060263635

TABLE 1-continued

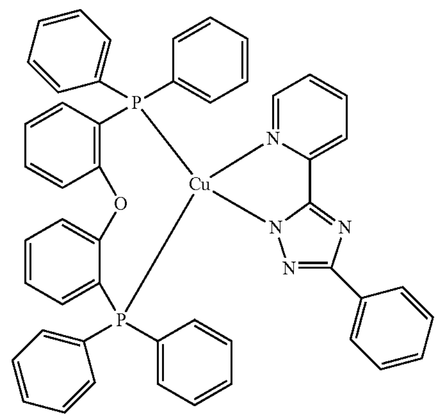
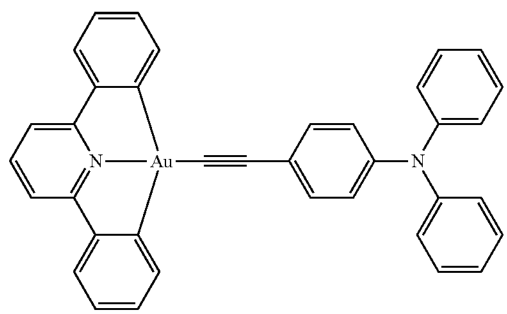
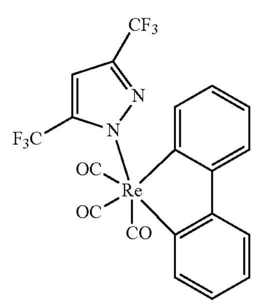
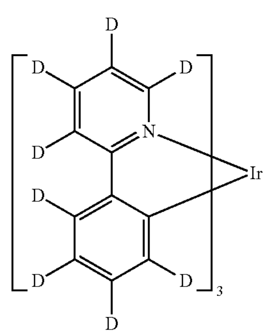
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Cu complexes		WO2009000673
Gold complexes		Chem. Commun. 2906 (2005)
Rhenium (III) complexes		Inorg. Chem. 42, 1248 (2003)
Deuterated organometallic complexes		US20030138657

TABLE 1-continued

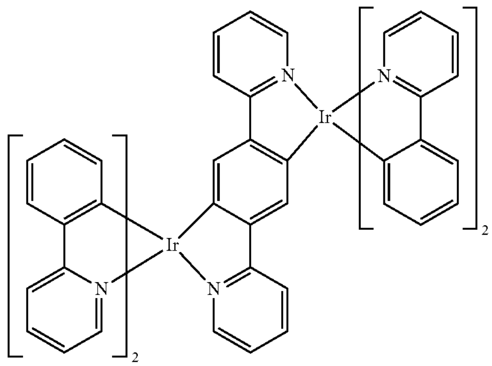
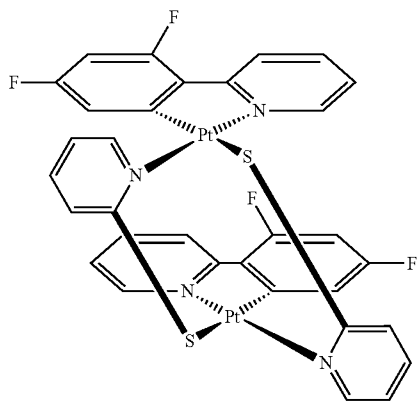
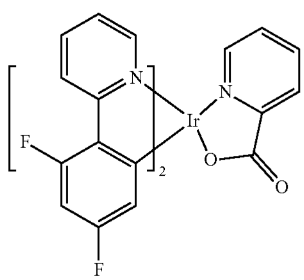
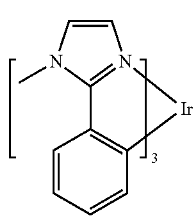
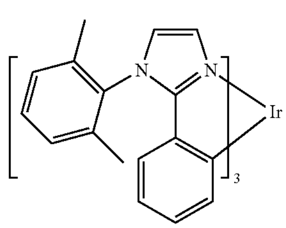
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Organometallic complexes with two or more metal centers		US20030152802
		U.S. Pat. No. 7,090,928
Blue dopants		
Iridium (III) organometallic complexes		WO2002002714
		WO2006009024
		US20060251923

TABLE 1-continued

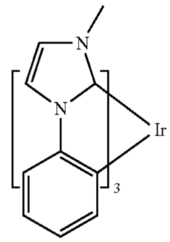
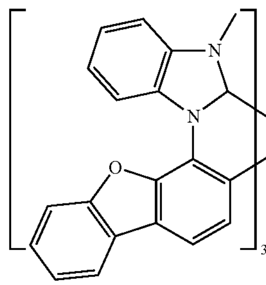
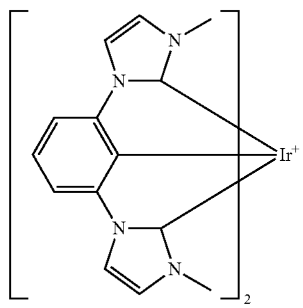
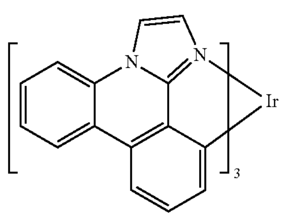
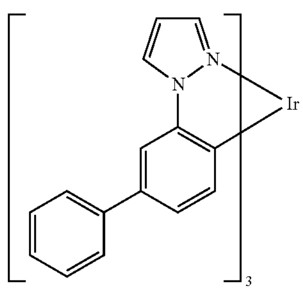
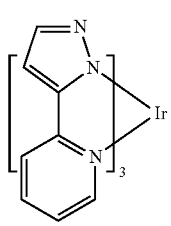
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		U.S. Pat. No. 7,393,599, WO2006056418, US20050260441, WO2005019373
		U.S. Pat. No. 7,534,505
		U.S. Pat. No. 7,445,855
		US20070190359, US20080297033
		U.S. Pat. No. 7,338,722
		US20020134984

TABLE 1-continued

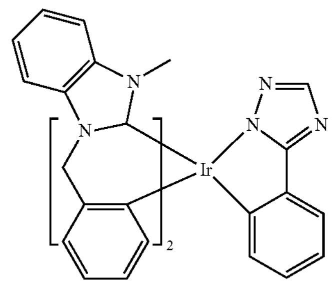
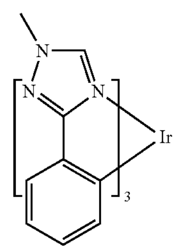
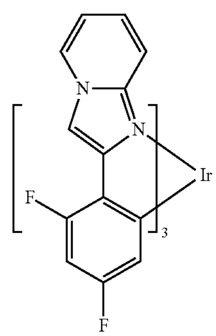
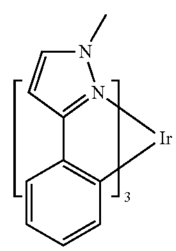
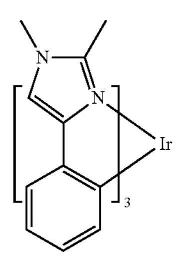
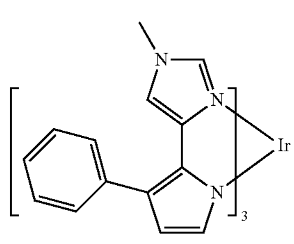
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		Angew. Chem. Int. Ed. 47, 1 (2008)
		Chem. Mater. 18, 5119 (2006)
		Inorg. Chem. 46, 4308 (2007)
		WO2005123873
		WO2005123873
		WO2007004380

TABLE 1-continued

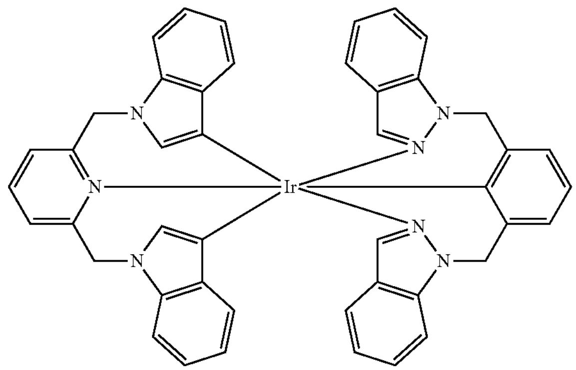
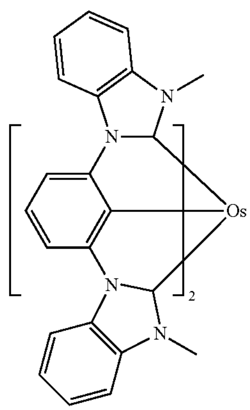
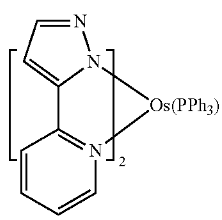
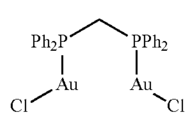
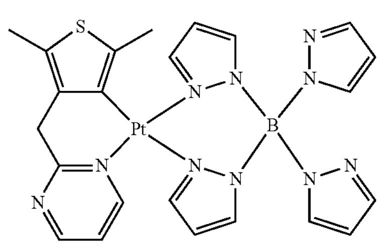
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		WO2006082742
Osmium (II) complexes		U.S. Pat. No. 7,279,704
		Organometallics 23, 3745 (2004)
Gold complexes		Appl. Phys. Lett.74, 1361 (1999)
Platinum (II) complexes		WO2006098120, WO2006103874

TABLE 1-continued

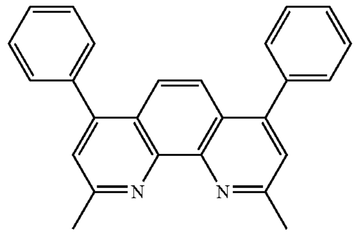
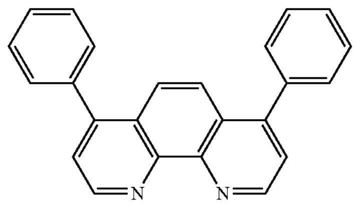
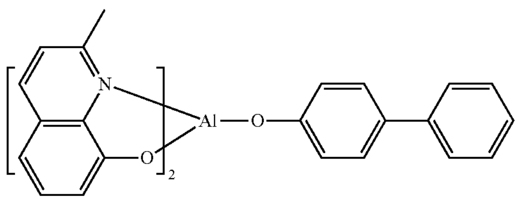
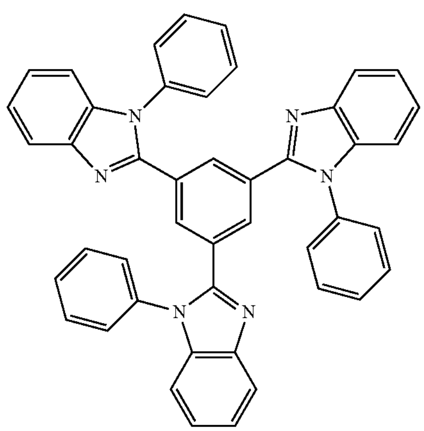
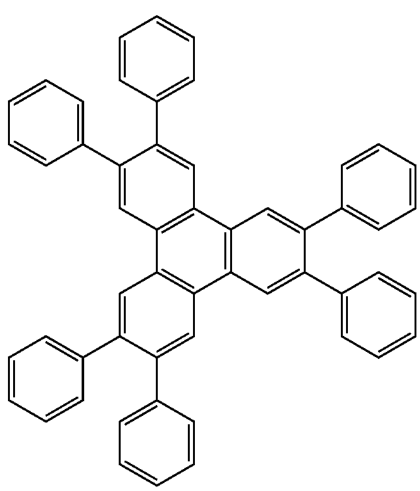
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Exciton/hole blocking layer materials		
Bathocuprine compounds (e.g., BCP, BPhen)		Appl. Phys. Lett. 75, 4 (1999)
		Appl. Phys. Lett. 79, 449 (2001)
Metal 8-hydroxyquinolates (e.g., BAlq)		Appl. Phys. Lett. 81, 162 (2002)
5-member ring electron deficient heterocycles such as triazole, oxadiazole, imidazole, benzoimidazole		Appl. Phys. Lett. 81, 162 (2002)
Triphenylene compounds		US20050025993

TABLE 1-continued

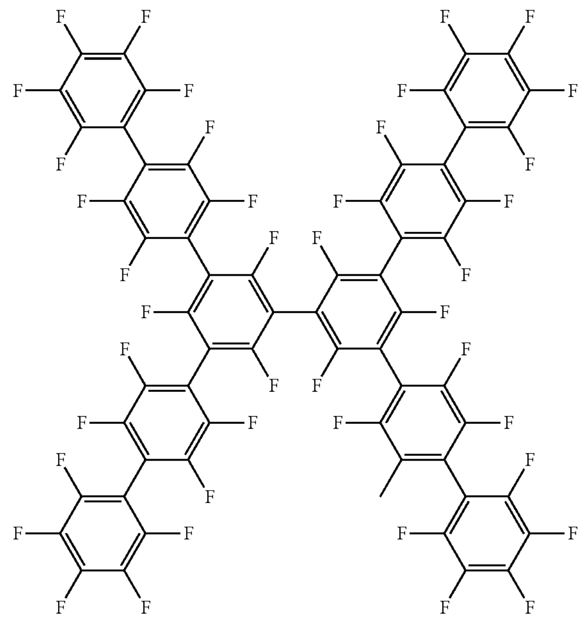
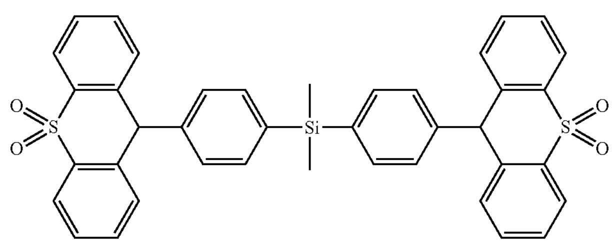
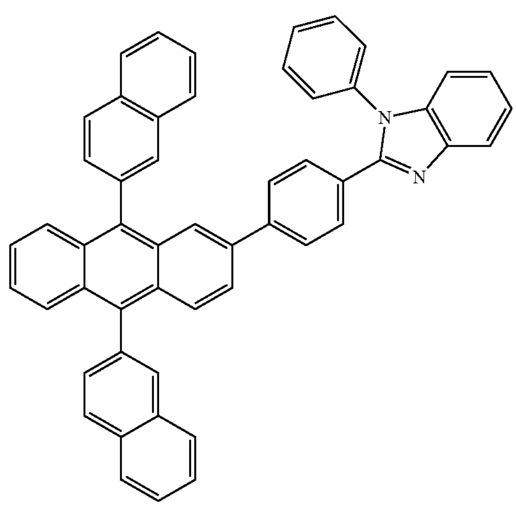
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Fluorinated aromatic compounds		Appl. Phys. Lett. 79, 156 (2001)
Phenothiazine-S-oxide		WO2008132085
Electron transporting materials		
Anthracene-benzoimidazole compounds		WO2003060956

TABLE 1-continued

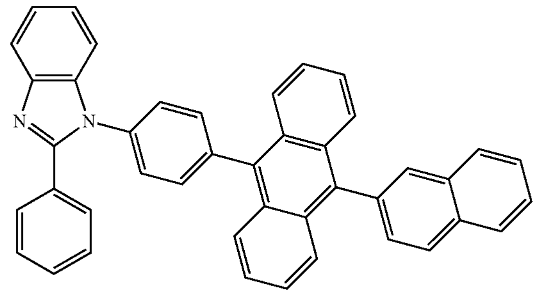
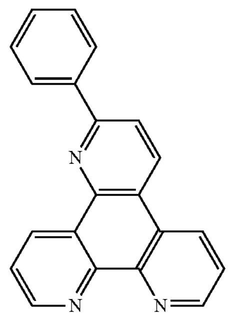
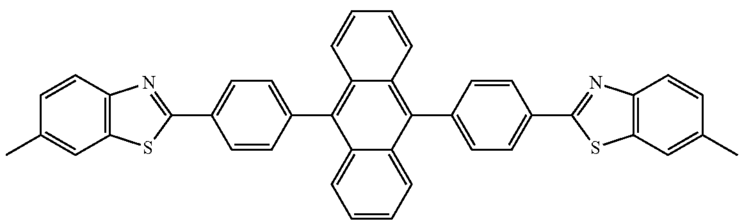
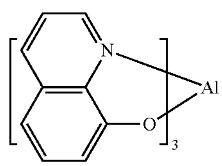
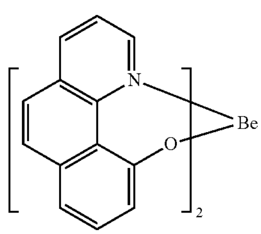
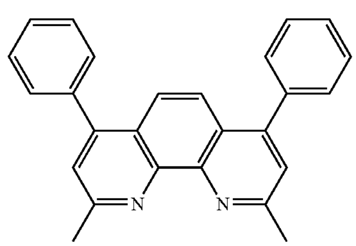
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US20090179554
Aza triphenylene derivatives		US20090115316
Anthracene-benzothiazole compounds		Appl. Phys. Lett. 89, 063504 (2006)
Metal 8-hydroxyquinolates (e.g., Alq_3, Zrq_4)		Appl. Phys. Lett. 51, 913 (1987) U.S. Pat. No. 7,230,107
Metal hydroxybenoquinolates		Chem. Lett. 5, 905 (1993)
Bathocuprine compounds such as BCP, BPhen, etc		Appl. Phys. Lett. 91, 263503 (2007)

TABLE 1-continued

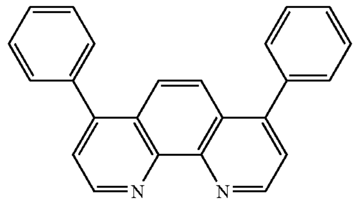
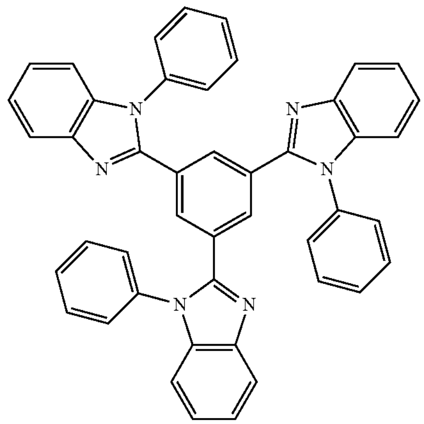
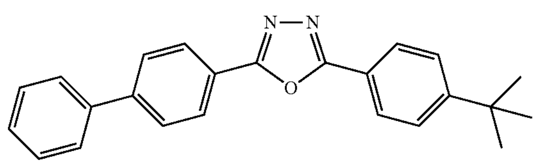
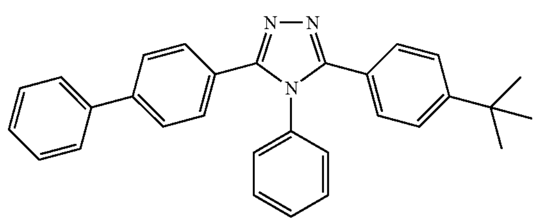
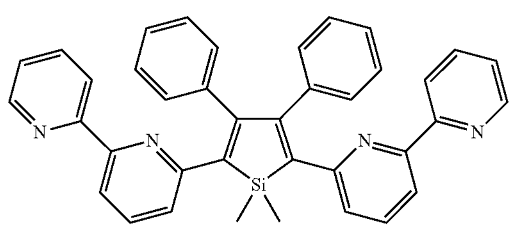
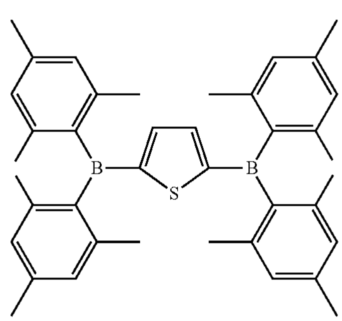
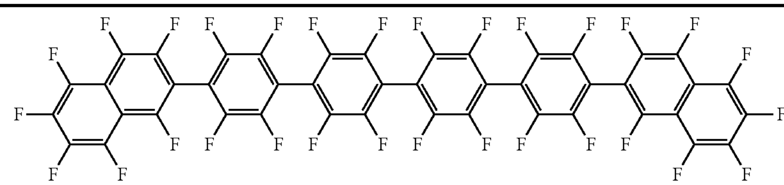
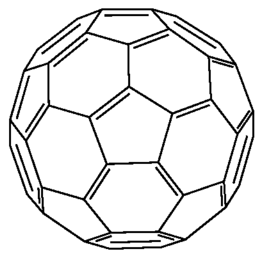
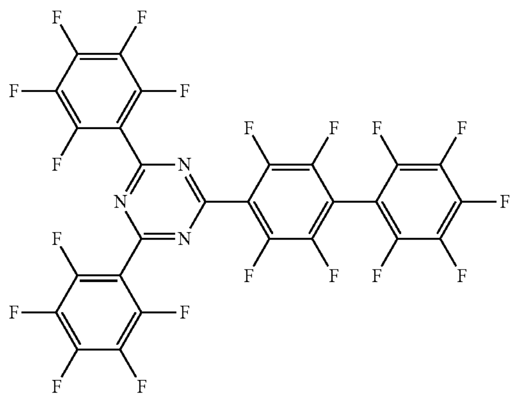
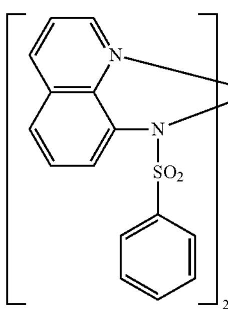
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		Appl. Phys. Lett. 79, 449 (2001)
5-member ring electron deficient heterocycles (e.g., triazole, oxadiazole, imidazole, benzoimidazole)		Appl. Phys. Lett. 74, 865 (1999)
		Appl. Phys. Lett. 55, 1489 (1989)
		Jpn. J. Apply. Phys. 32, L917 (1993)
Silole compounds		Org. Electron. 4, 113 (2003)
Arylborane compounds		J. Am. Chem. Soc. 120, 9714 (1998)

TABLE 1-continued

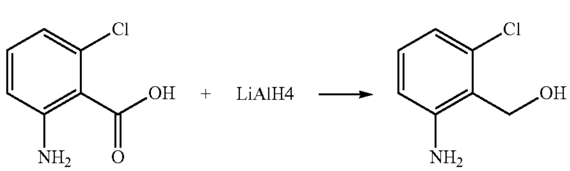
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Fluorinated aromatic compounds		J. Am. Chem. Soc. 122, 1832 (2000)
Fullerene (e.g., C60)		US20090101870
Triazine complexes		US20040036077
Zn (N^N) complexes		U.S. Pat. No. 6,528,187

EXPERIMENTAL

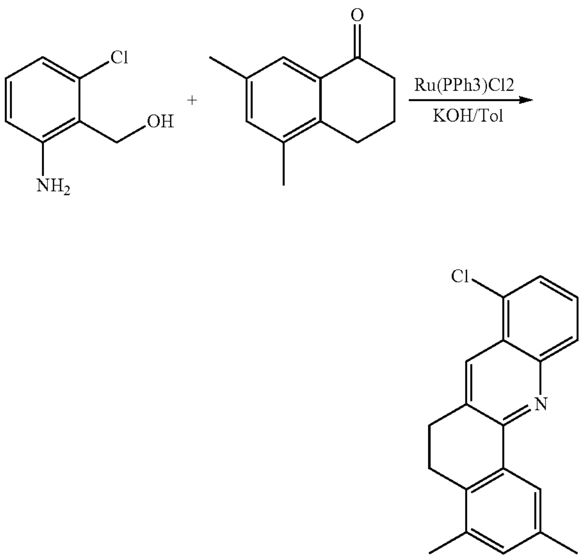
Compound Examples

Example 1

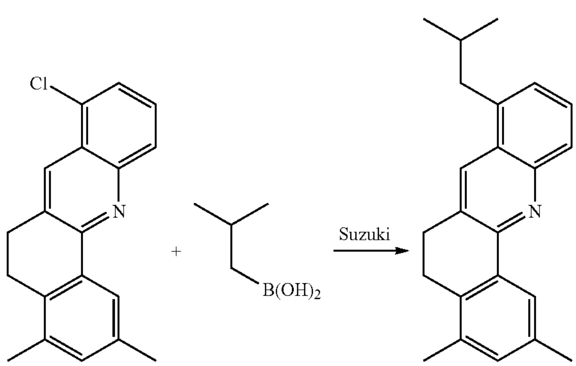
Synthesis Of Compound 9



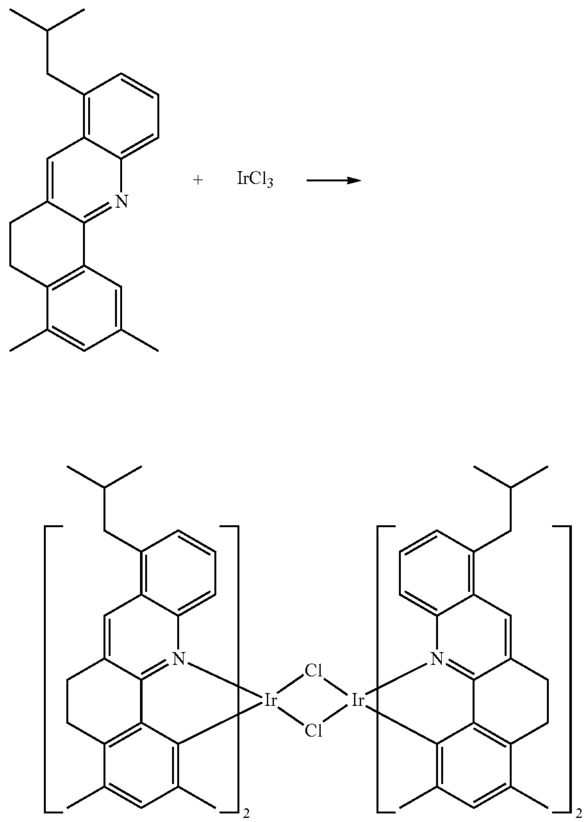
Synthesis of (2-amino-6-chlorophenyl)methanol. 2-Amino-6-chlorobenzoic acid (25.0 g, 143 mmol) was dissolved in 120 mL of anhydrous THF in a 500 mL 2 neck round bottom flask. The solution was cooled in an ice-water bath. 215 mL of 1.0 M lithium aluminum hydride (LAH) THF solution was then added dropwise. After all of the LAH was added, the reaction mixture was allowed to warm up to room temperature and stirred at room temperature for overnight. ~10 mL of water was added to the reaction mixture followed by 7 g 15% NaOH. An additional 20 g of water was added to the reaction mixture. Decant the organic THF phase and the solid was added with ethyl acetate. ~200 mL and stirring and combined ethyl acetate organic portion and THF portion and added Na_2SO_4 drying agent. The mixture was filtered and evaporated. ~20 g yellow solid was obtained without further purification for next step reaction.



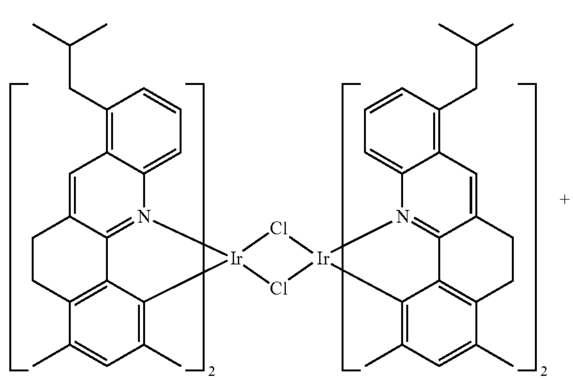
Synthesis of 8-chloro-2,4-dimethyl-5,6-dihydrobenzo[c]acridine. (2-Amino-6-chlorophenyl)methanol (16 g, 101 mmol), 5,7-dimethyl-3,4-dihydronaphthalen-1(2H)-one (20.0 g, 111 mmol), $RuCl_2(PPh_3)_3$ (0.971 g, 1.01 mmol), and KOH (5.7 g, 101 mmol) were refluxed in 200 mL of toluene for 12 h. Water was collected from the reaction using a Dean-stark trap. The reaction mixture was allowed to cool to room temperature and filtered through a silica gel plug and eluted with dichloromethane. The product was washed by methanol and recrystallized from hexane to obtain ~20 gram of the desired product which was confirmed by GC-MS.



Synthesis of 8-isobutyl-2,4-dimethyl-5,6-dihydrobenzo[c]acridine. 8-chloro-2,4-dimethyl-5,6-dihydrobenzo[c]acridine (15.0 g, 51.1 mmol), isobutylboronic acid (7.8 g, 77 mmol), dicyclohexyl(2',6'-dimethoxy-[1,1'-biphenyl]-2-yl)phosphine (1.6 g, 4.08 mmol) potassium phosphate monohydrate (41.2 g, 179 mmol) were mixed in 300 mL of toluene. The system was degassed for 20 minutes. $Pd_2(dba)_3$ (0.93 g, 1.02 mmol) was then added and the system was refluxed overnight. After cooling to room temperature, the reaction mixture was filtered through a Celite® plug and eluted with 30% ethyl acetate in toluene. ~19.5 crude liquid was obtained. The crude product was recrystallized from 5% acetone in hexane to obtain ~14.9 g pure product (99.6%) which was confirmed by GC-MS.



Synthesis of iridium dimmer. A mixture of 8-isobutyl-2,4-dimethyl-5,6-dihydrobenzo[c]acridine (11.5 g, 36.5 mmol), $IrCl_3.4H_2O$ (4.5 g, 12.2 mmol), 2-ethoxyethanol (90 mL) and water (30 mL) was refluxed under nitrogen overnight. The reaction mixture was filtered and washed with MeOH (3×20 mL) ~9 g of dimer was obtained after vacuum drying. The dimer was used for the next step without further purification.



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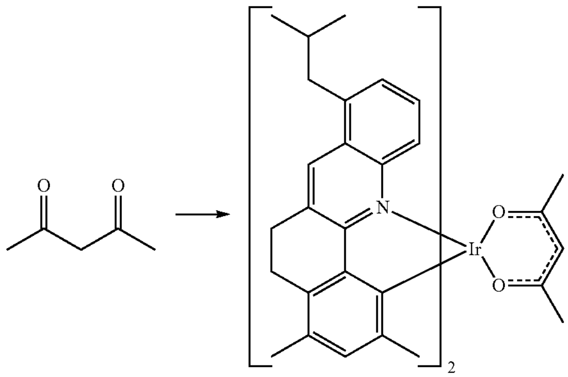


Compound 9

Synthesis of Compound 9. Dimer (3.5 g, 2.07 mmol), pentane-2,4-dione (2.07 g, 20.7 mmol), Na_2CO_3 (2.19 g, 20.7 mmol) and 2-ethoxyethanol (100 mL) were stirred at room temperature for 24 h. The precipitate was filtered and washed with methanol. The solid was further purified by passing it through a silica gel plug (that was pretreated with 15% TEA in hexanes) and eluted with methylene chloride. 0.6 g of product Compound 9 was obtained after purification. The compound was confirmed by LC-MS.

Example 2

Synthesis Of Compound 10

Compound 10 was synthesized in same way as Compound 9, and confirmed by LC-MS.

Device Examples

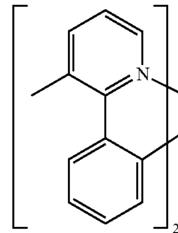
All example devices were fabricated by high vacuum ($<10^{-7}$ Torr) thermal evaporation. The anode electrode is 1200 Å of indium tin oxide (ITO). The cathode consisted of 10 Å of LiF followed by 1,000 Å of Al. All devices are encapsulated with a glass lid sealed with an epoxy resin in a nitrogen glove box (<1 ppm of H_2O and O_2) immediately after fabrication, and a moisture getter was incorporated inside the package.

The organic stack of the Device Examples consisted of sequentially, from the ITO surface, 100 Å of Compound A as the hole injection layer (HIL), 300 Å of 4,4'-bis[N-(1-naphthyl)-N-phenylamino]biphenyl (α-NPD) as the hole transporting layer (HTL), 300 Å of the invention compound doped in BAlq as host with 4, 6 or 8 wt % of an Ir phosphorescent compound as the emissive layer (EML), 500 or 550 Å of Alq_3 (tris-8-hydroxyquinoline aluminum) as the ETL.

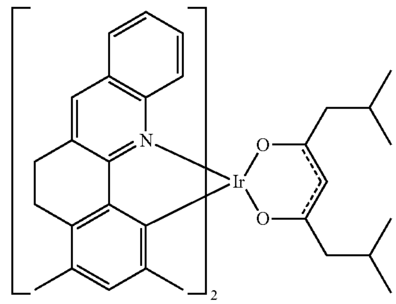
Comparative Device Examples with Compound B was fabricated similarly to the Device Examples, except that Compound B is used as the emitter in the EML.

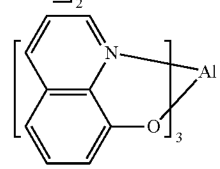
As used herein, Compound A, Compound B and other compounds used in the device examples have the following structures:

Compound A

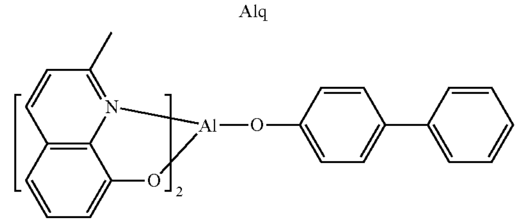


Compound B

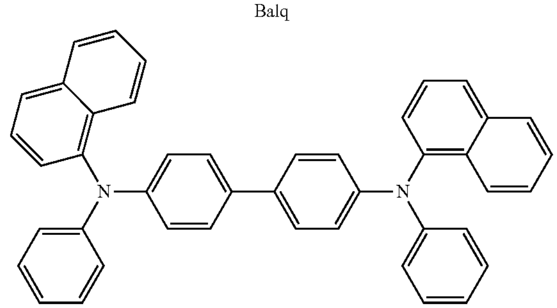




Alq



Balq



NPD

The device structures are summarized in Table 2, and the device data is summarized in Table 3. Cmpd. is an abbreviation of Compound. Ex. is an abbreviation of Example. Comp. Ex. is an abbreviation of Comparative Example.

TABLE 2

Example	HIL	HTL	EML (doping %)		ETL
Ex. 1	Compound A	NPD	Balq	Compound 10 7%	Alq
Ex. 2	Compound A	NPD	Balq	Compound 9 8%	Alq
Comp. Ex. 1	Compound A	NPD	Balq	Compound B 8%	Alq

TABLE 3

					At 1000 nits				At 2000 nits
Cmpd.	x	y	λ_{max} [nm]	FWHM [nm]	Voltage [V]	LE [cd/A]	EQE [%]	PE [lm/W]	$LT_{97\%}$ [Hr]
Ex. 1	0.649	0.348	612	54	8.9	12.5	10.1	4.4	29.9
Ex. 2	0.656	0.341	616	62	8.8	8.5	8.0	3.0	8.5
Comp. Ex. 1	0.651	0.346	612	60	9.7	9.9	8.6	3.2	9.5

Table 3 is a summary of the device data. The luminous efficiency (LE), external quantum efficiency (EQE) and power efficiency (PE) were measured at 1000 nits, while the lifetime ($LT_{97\%}$) was defined as the time required for the device to decay to 97% of its initial luminance at 2000 nits under a constant current density.

As seen from Table 3, the EQE measured at 1000 nits for a device comprising Compound 10 is 17% higher than the EQE measured for a device comprising Compound B. Additionally, the EL spectral full width at half maximum (FWHW) of Compound 10 is also narrower than the FWHM of Compound B, i.e, FWHM of Compound 10 is 54 nm, while the FWHM of Compound B is 60 nm. The FWHM of Compound 9, however, is similar to the FWHM of Compound B. It is a desirable device property to have a narrow FWHM. These results indicate that Compound 10 is a more efficient red emitter than Compounds B with a desirable narrower FWHM.

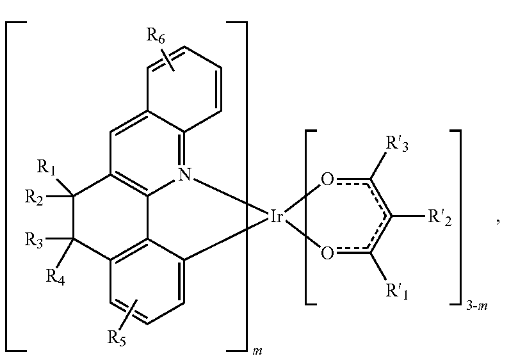
Compound 10 also has a longer lifetime than Compound B, i.e., the $LT_{97\%}$ measured at room temperature for Compound 10 is about three times as long as the $LT_{97\%}$ measured at room temperature for Compound B. Compound 10 differs from Compound B in that it has a bulkier substituent on quinoline ring. Therefore, devices comprising a compound with a substituent on the quinoline ring may have significantly improved performance.

It is understood that the various embodiments described herein are by way of example only, and are not intended to limit the scope of the invention. For example, many of the materials and structures described herein may be substituted with other materials and structures without deviating from the spirit of the invention. The present invention as claimed may therefore include variations from the particular examples and preferred embodiments described herein, as will be apparent to one of skill in the art. It is understood that various theories as to why the invention works are not intended to be limiting.

The invention claimed is:

1. A compound of formula III

Formula III



wherein each of R_1, R_2, R_3, R_4 R_5, R_1', R_2', and R_3' are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof;

wherein each R_6 is independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, and combinations thereof;

wherein at least one R_6 is selected from the group consisting of alkyl comprising more than 2 carbon atoms, aryl, and silyl;

wherein any two adjacent R_1, R_2, R_3, and R_4 are optionally linked to form an alkylene ring;

wherein R_5 may represent mono, di or tri substitutions;

wherein R_6 may represent mono, di, tri, or tetra substitutions; and

wherein m is 1 or 2.

2. The compound of claim **1**, wherein at least one of R_1, R_2, R_3 and R_4 is an alkyl.

3. The compound of claim **1**, wherein at least one of R_1, R_2, R_3 and R_4, is an alkyl having more than 2 carbon atoms.

4. The compound of claim **1**, wherein at least one of R_1, R_2, R_3, R_4, and R_6 is isobutyl.

5. The compound of claim **1**, wherein at least one of R'_1, R'_2, and R'_3 contains a branched alkyl moiety with branching at a position further than the α position to the carbonyl group.

6. The compound of claim **1**, wherein at least one of R'_1 and R'_3 is isobutyl.

7. The compound of claim **1**, wherein R'_2 is hydrogen.

8. The compound of claim **1**, wherein each R_6 is selected from the group consisting of alkyl, cycloalkyl, heteroalkyl, arylalkyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, and heteroaryl; and

wherein at least one R_6 is selected from the group consisting of alkyl comprising more than 2 carbon atoms, aryl, and silyl.

9. The compound of claim **1**, wherein the compound is selected from the group consisting of:

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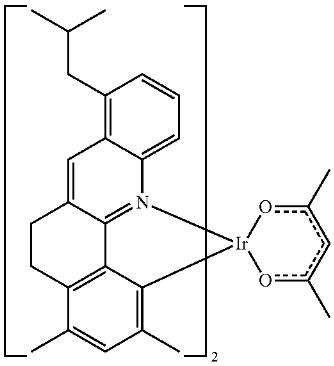

, and

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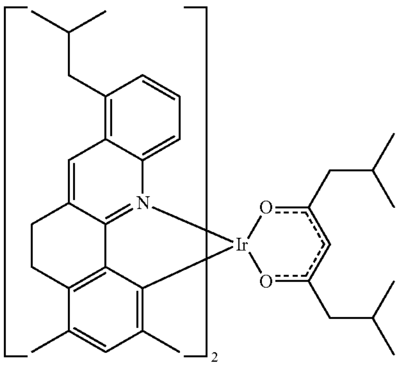

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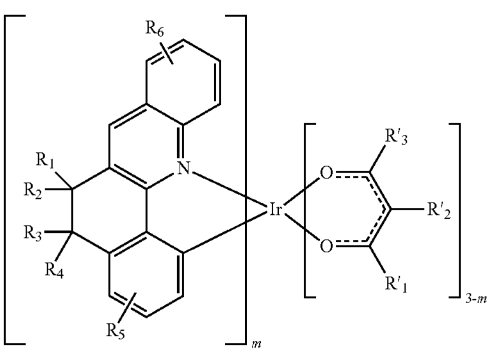
10. A first device comprising a first organic light emitting device, comprising:

an anode;

a cathode; and

an organic layer, disposed between the anode and the cathode, comprising a compound of Formula III:

Formula III



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wherein each of R_1, R_2, R_3, R_4 R_5, R_1', R_2', and R_3' are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof;

wherein each R_6 is independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, and combinations thereof;

wherein at least one R_6 is selected from the group consisting of alkyl comprising more than 2 carbon atoms, aryl, and silyl;

wherein any two adjacent R_1, R_2, R_3, and R_4 are optionally linked to form an alkylene ring;

wherein R_5 may represent mono, di or tri substitutions;

wherein R_6 may represent mono, di, tri, or tetra substitutions; and

wherein m is 1 or 2.

11. The first device of claim **10**, wherein the first device is a consumer product.

12. The first device of claim **10**, wherein the first device is an organic light emitting device.

13. The first device of claim **10**, wherein the first device comprises a lighting panel.

14. The first device of claim **10**, wherein the organic layer is an emissive layer and the compound is an emissive dopant.

15. The first device of claim **10**, wherein the organic layer further comprises a host.

16. The first device of claim **15**, wherein the host is a metal 8-hydroxyquinolate.

17. A compound selected from the group consisting of

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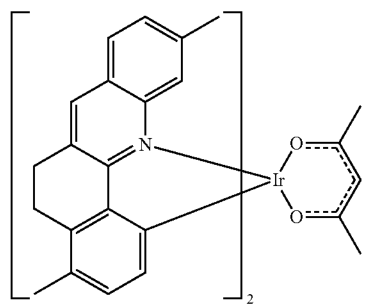

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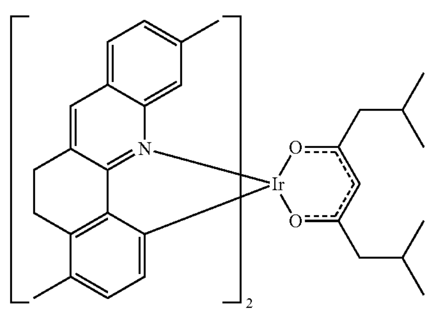

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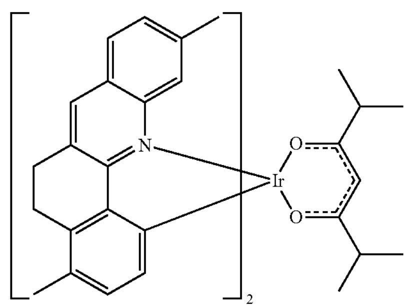

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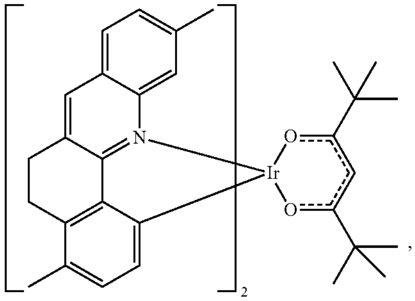

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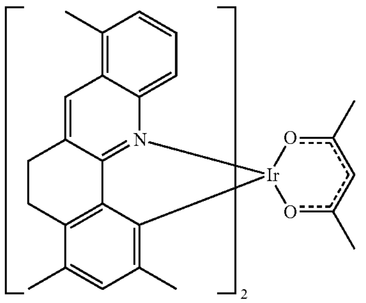

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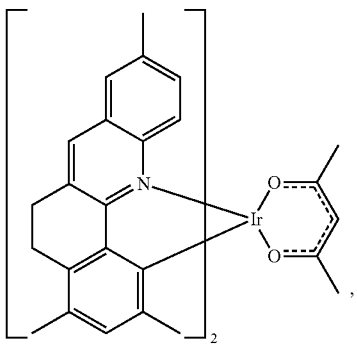

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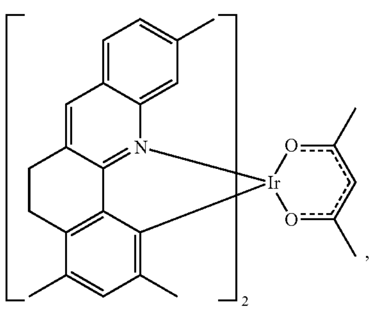

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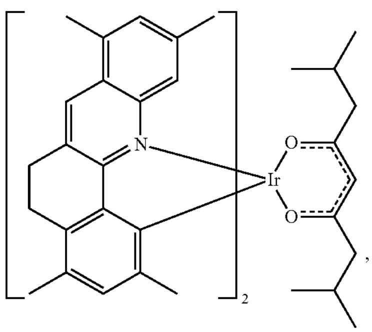

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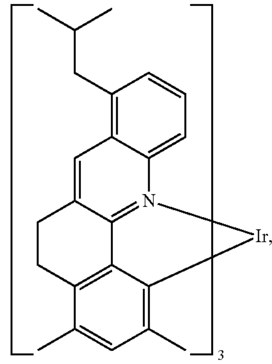

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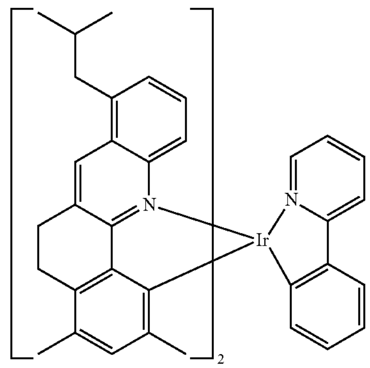

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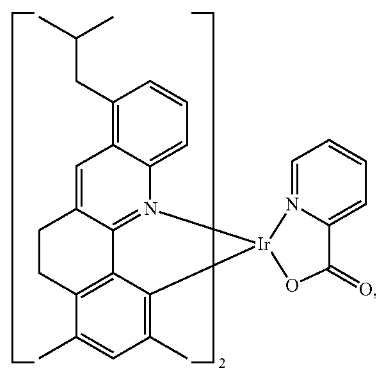

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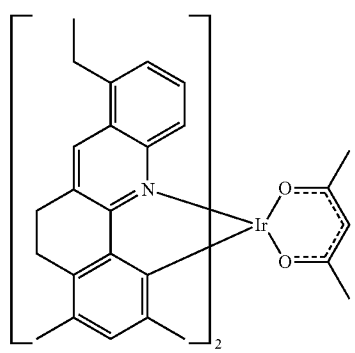

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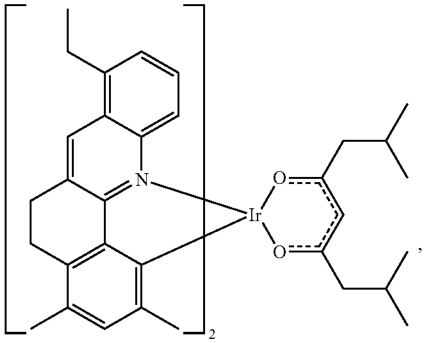

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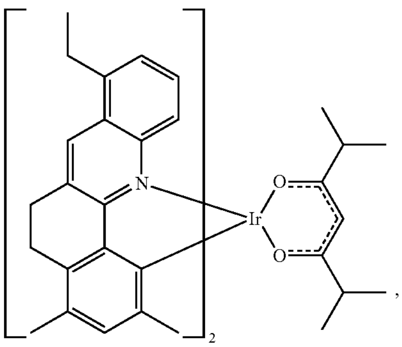

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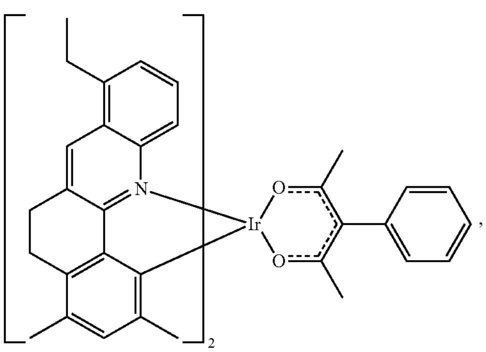

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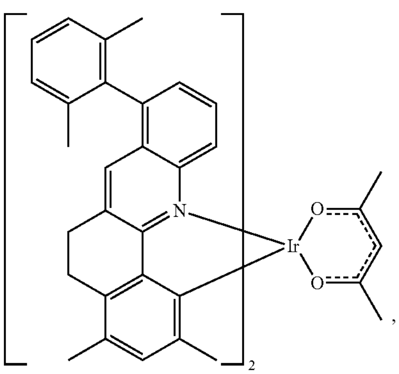

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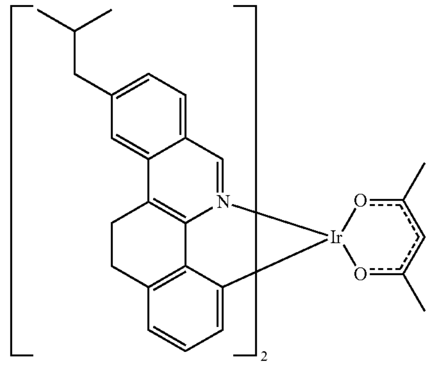

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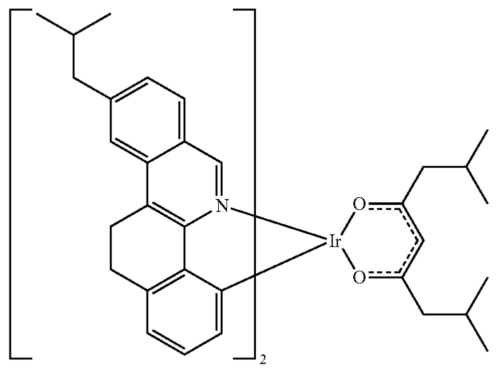

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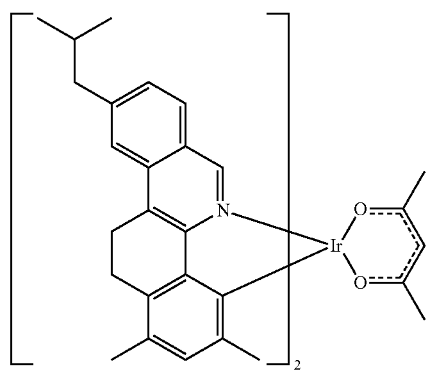

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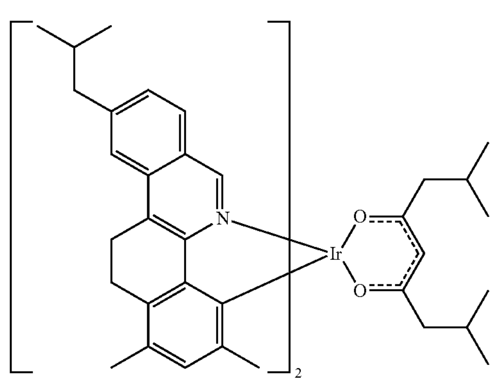

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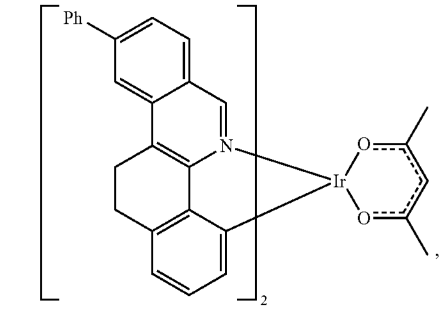

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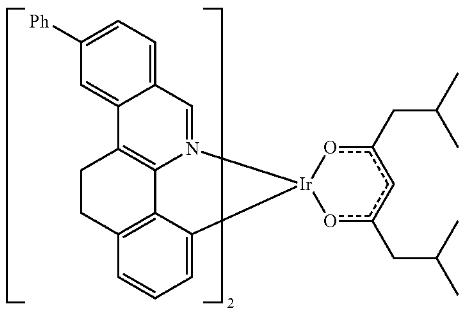

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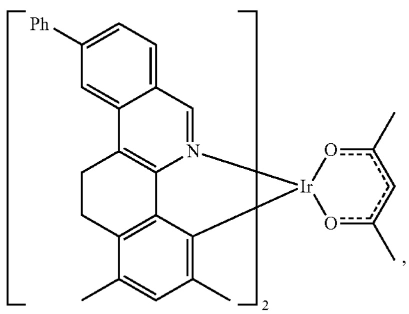

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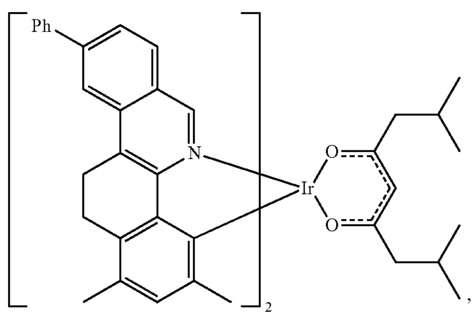

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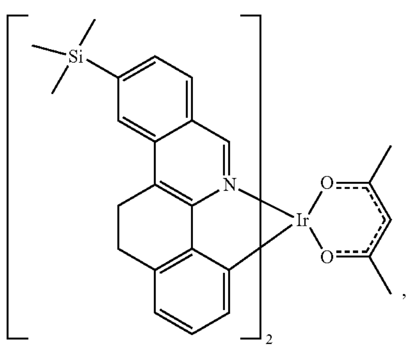

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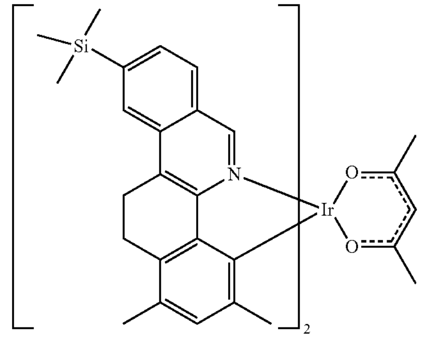

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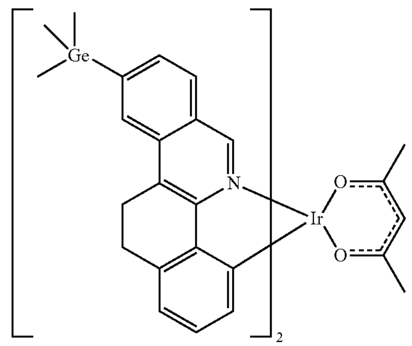

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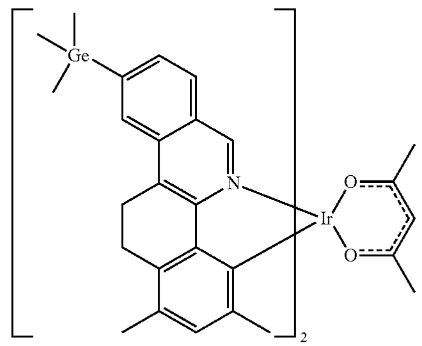

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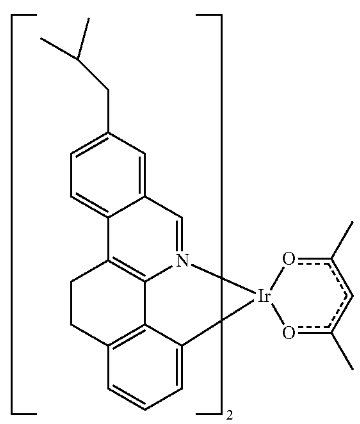

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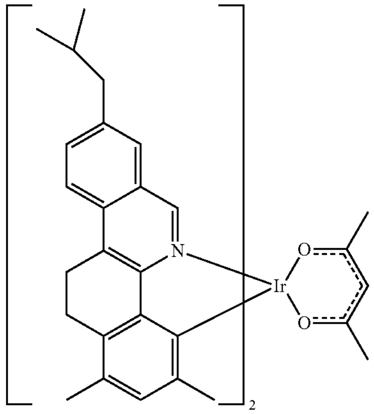
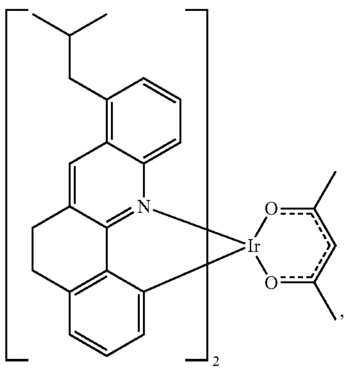


18. The compound of claim 1, wherein the compound is selected from the group consisting of:

1



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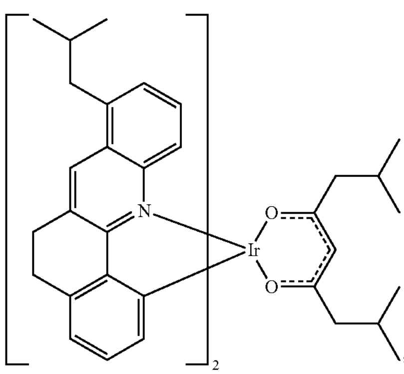

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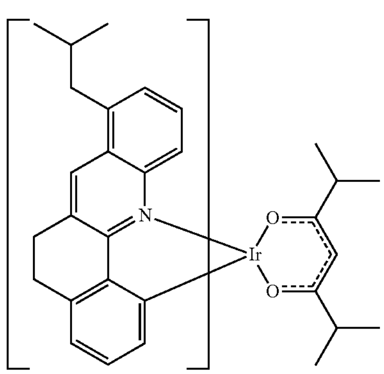

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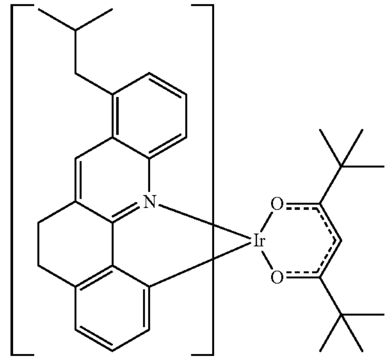

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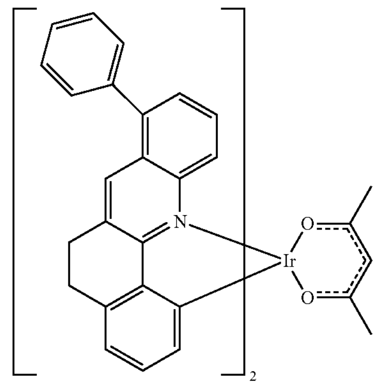

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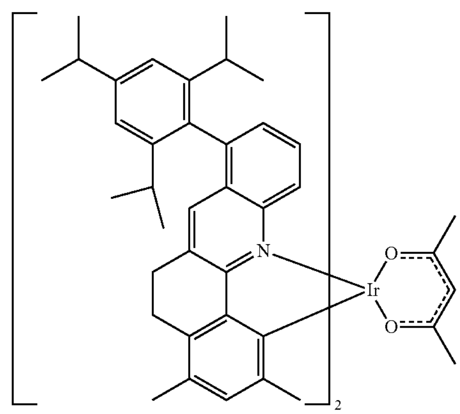

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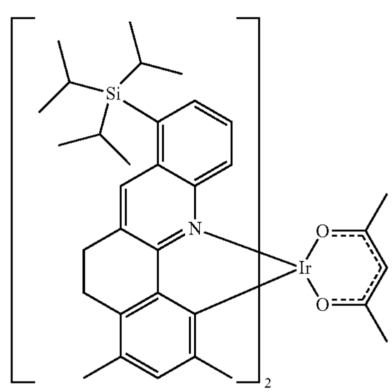

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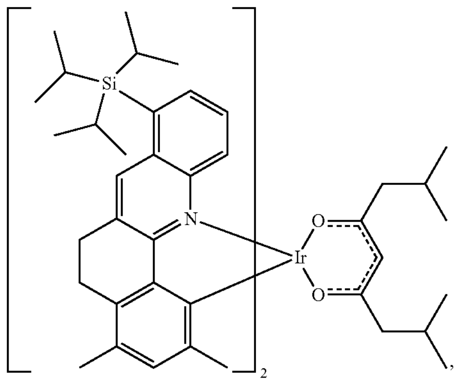

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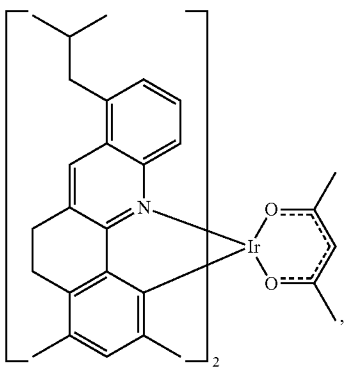

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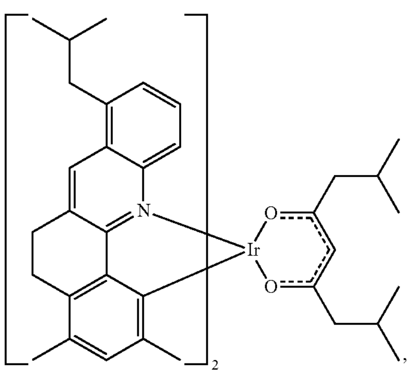

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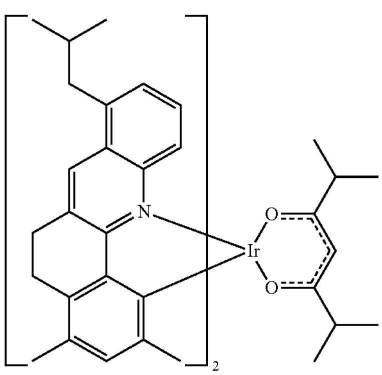

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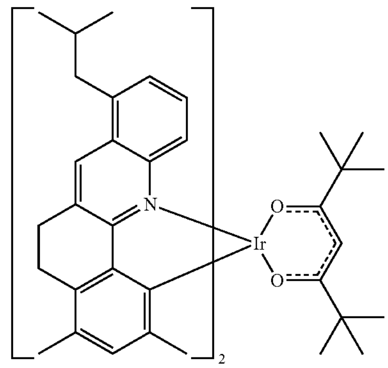

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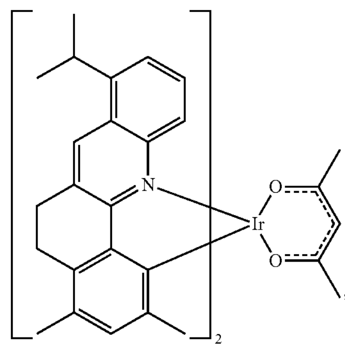

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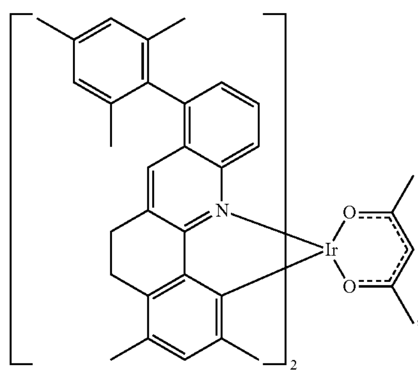

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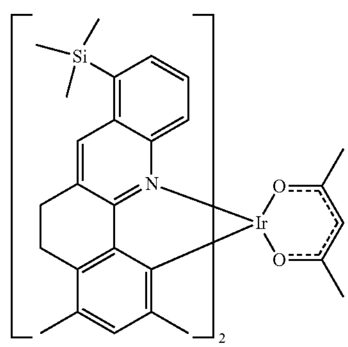

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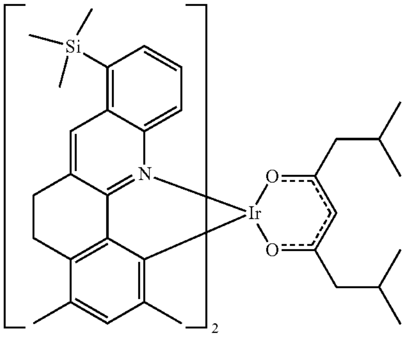

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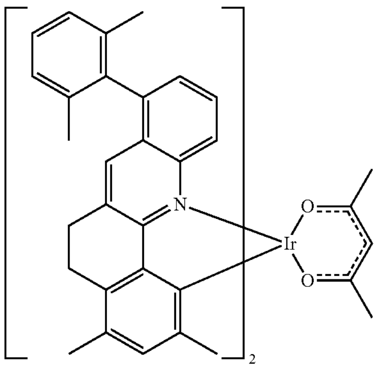

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

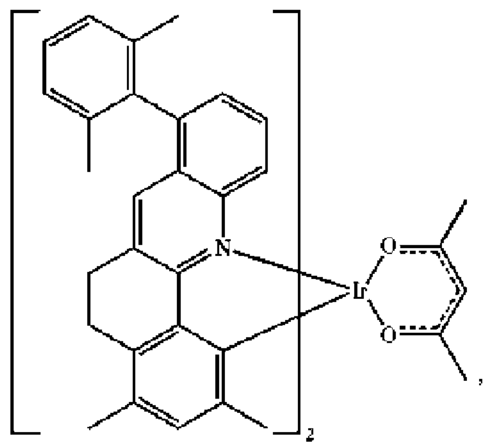
PATENT NO. : 9,190,621 B2
APPLICATION NO. : 13/872364
DATED : November 17, 2015
INVENTOR(S) : Bin Ma et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Claims:

Claim 17, Column 115, Lines 52-65, delete

32

“  ”

Signed and Sealed this
Twelfth Day of April, 2016

Michelle K. Lee
Director of the United States Patent and Trademark Office